PROCESS SIMULATION AND ECONOMIC EVALUATION

OF A SOLAR POWER PLANT

USING ASPEN

by

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SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF

BACHELOR OF SCIENCE IN CHEMICAL ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1980

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ABSTRACT

The ASPEN process simulator and economic evaluation system were used to study the operating parameters and economic feasability of a 100 megawatt solar power plant. The system evaluated was the steam rankine cycle used in modern fossil fueled power plants, but fired by a central solar receiver and heliostat collector system. Plant size corresponds to an early commercial plant rather than a developmental pilot plant or large commercial plant. Fluid flowrate, and heating and power requirements for a typical plant cycle were determined using the ASPEN simulator subsystem. Results corresponded closely to process parameters for existing power plants.

Economic analysis included capital and operating cost determination, equipment sizing, and profitability analysis. ASPEN results agreed with Department of Energy studies which showed the solar power generation concept to be a factor of two away from competitive selling price.

Thesis Supervisor : David K. Dyck

ACKNOWLEDGEMENTS

Sincerest thanks are due

David K. Dyke, who advised me throughout this project and invested much of his time to get the costing and economic evaluation routines working correctly;

Fred Zeigler, the master debugger who had all the answers;

the rest of the ASPEN staff, who were a valuable resource;

Eric, who provided access to the word processor which greatly eased the typing;

and Julie, who helped in many ways.

1 INTRODUCTION

1.1 ASPEN

ASPEN (Advanced System for Process ENgineering) is being developed at MIT by the Chemical Engineering Department and Energy Laboratory for use in evaluating fossil energy conversion processes. It is designed to enable rapid calculation of process heat and material balances, preliminary equipment sizing, and process economic evaluations for a wide variety of chemical engineering problems. It has the capability to handle solids, multiphase streams, and complex substances such as coal (1).

1.2 The Problem

As part of the development and testing proceedure, a variety of example problems are being analyzed on ASPEN to demonstrate its problem solving ability. This thesis involves the study of the steam cycle used in modern fossil fueled electric power plants, but as applied to the specific case of a solar powered installation. The energy conversion process is simulated on ASPEN and several process parameters are optimized. Estimates of size and cost are developed for major pieces of equipment, and an evaluation of economic profitability is carried out. There are a number of interesting characteristics pertinent to this study:

(1) The process is a closed cycle, involving no material feed or product streams.

(2) It requires physical property calculations for water over a wide range of temperature and pressure, ranging from supercritical steam to highly compressed liquid.

(3) Process parameters are manipulated during the analysis to achieve specified flowsheet criteria.

(4) The flowsheet simulation and convergence, equipment costing, and economic analysis are all studied together, in one program.

(5) Economic evaluation of the solar power plant is achieved by specifying a product (electricity) selling price and required rate of return, and then iteratively converging upon an additional capital cost above that of the basic cycle to determine the dollar amount available for investment in the solar collector equipment.

1.3 Application of Solar Energy to Power Generation

The development of a solar power generation plant is interesting for a number of reasons:

(1) The use of solar energy has no operating fuel requirements associated with it which contrasts sharply against high priced fossil fuels.

(2) This source of energy is nonpolluting and is truly renewable.

(3) Whereas fossil fuels often are found in hard to reach places far from the user, solar is very widely accessible.

Generating electricity from solar energy facilitates convenient distribution of the harnessed energy through the power grid. This is an important point because arid regions where solar insolation is heaviest may not have sufficient demand for produced power.

Applying a solar input to a steam cycle heat engine is attractive because this type of conversion process is well developed and has been optimized to achieve relatively high thermal efficiencies, on the order of 45 percent. This feature reduces development time and effort for a working system, whereas other conversion methods, such as photovoltaic and photochemical processes, require much more study before sufficient efficiencies will be reached. Also, heat engines are most efficient at large sizes, a fact which correlates well with the need for economies of scale in the solar collection and concentration subsystem.

Along with the advantages to the solar power cycle concept come several problems. An extensive collection system is required to gather and concentrate the sun's rays into a heat source capable of producing the required boiler temperatures of 1000 degrees Fahrenheit, and a sophisticated control system is needed to track the diurnal movement of the the sun.

Both of these needs translate into a large capital investment required for a solar installation. The U.S. Department of Energy estimates that a solar power plant would require a capital investment in the neighborhood of 4200 dollars per kilowatt (KW) of capacity (2) versus a figure of 750 dollars per KW for a coal plant, and 850 $/KW for a nuclear fired plant (3). This large sunk cost at the beginning of a project increases its risk significantly. Uncertainty is compounded by the fact that this venture trades fossil fuel cost for increased construction costs. Both the price of fuel and capital are very volatile in today's markets. Therefore it is important to be able to quickly make accurate economic evaluations of the venture. This need can be filled by implementing equipment costing and economic evaluation for the venture on a computerized economic evaluation system such as ASPEN.

1.4 Solar Subsystem Design

The U.S. Department of Energy has chosen the central receiver concept to be the most promising alternative for commercial solar power generation. It consists of a field of individually guided mirrors (heliostats) that collect and redirect the sun's energy to a receiver mounted on top of a tower. A schematic of the system is shown in Figure 1. In the receiver, the radiant solar energy is absorbed by circulating water which vaporizes into high pressure steam used to drive a generating turbine. To achieve the high temperatures required by the steam boiler, incident solar radiation must be concentrated by a factor of up to 1000. A 100 MW power plant would need approximately 7000 heliostats of forty square meters each, spread over an area of one half square mile (4). In order to prevent transmitance blockage by adjacent heliostat structures, the receiver would have to be on top of a 1000 foot tall tower, located near the center of the field. A liquid and rock filled sensible heat storage container would also be included in the system to damp out fluctuations in heat input and to extend the effective generation period per day.

2 STEAM CYCLES

2.1 Theory

2.1.1 Rankine Cycle

Modifications of the rankine cycle are used today in a majority of fossil fueled power plants. A process flowsheet and temperature - entropy diagram for the basic system are shown in Figure 2. At locus 1, high pressure steam enters a turbine and is adiabatically expanded, producing work. In process 2 to 3, the depressurized vapor-liquid mixture is condensed to liquid: heat is removed at a constant low temperature. From 3 to 4, the saturated liquid is pumped up to high pressure, requiring work. The change from 4 to 4' is the heating up of the compressed liquid to saturation temperature, and process 4 to 1 is the vaporization process at a constant high temperature.

2.1.2 Efficiency

Maximum efficiency is achieved in a heat engine when heat is input to the system at the highest possible temperature, and removed at the lowest possible temperature, as shown in Equation 1.

$$\eta = \frac{T_{Q_H} - T_{Q_L}}{T_{Q_H}} = \frac{W}{Q}$$

Equation 1

The most efficient power cycle is the Carnot cycle, differing from the ideal Rankine cycle in that heat is input at a constant high temperature. This means that there is no heating of compressed liquid up to saturation temperature. The T-S diagram for a Carnot cycle is shown in Figure 2 by cycles 1-2-3'-4' or 1-2-3-4". The first involves extreme pressurization of the working fluid up to the turbine temperature, and the second requires compression of a vapor-liquid mixture into a saturated liquid state. Neither of these processes is practical with modern pumping equipment. Hence the Carnot cycle is not used.

It is clear from Figure 2.b that the Rankine cycle is not as thermally efficient as the Carnot cycle, because the average temperature of heat input is lowered during process 4-4'. Additional inefficiency is introduced into real heat engines due to irreversible processes and friction effects.

2.1.3 Improvements to Efficiency

Superheating

Heating the vapor above its saturation point as shown in Figure 3, improves efficiency by increasing the average temperature of heat input. It also helps eliminate moisture produced during expansion (process 1-2 is inside the vapor-liquid envelope), which causes erosion of turbine blades.

Reheating

Instead of expanding the high pressure steam completely in one turbine, one can expand it to a medium pressure, reheat up to a higher temperature, and finish the expansion. This process, shown in Figure 3, also increases the average temperature of heating and removes moisture.

Feed Water Heating

Using some high temperature steam to preheat the compressed boiler feed water before it enters the boiler is useful because it reduces the amount of heat from outside the process put into the system at a low temperature during heating up to saturation. Of course, some of this efficiency increase is lost because less steam is run through the turbine to produce power.

2.2 The Simulated Cycle

Power plants use all of the above improvements in their operating cycles. The combination of reheaters and feed water preheaters for a particular plant depends upon equipment and fuel costs, reliability requirements, and a variety of other factors. A typical process flow diagram for a commercial power plant is shown in Figure 4 (5).

The process chosen for study is outlined in Figure 5. It employs all of the basic components in the commercial cycle, and retains the important thermodynamic characteristics of the Rankine cycle. Temperatures and pressures for the various unit operations were based upon the process parameters in Figure 4.

In addition to the main simulation, a case study simulation was done for the simple Rankine cycle in Figure 2. The purpose of this analysis was to compare efficiencies for cycles with and without reheat and feed water heat capability. Flowsheet parameters were set to match the main simulation.

3 ASPEN PROCESS SIMULATION

3.1 The Flowsheet Model

Figure 6 is an outline of the process block flowsheet. This diagram shows the connectivity between unit operations blocks and material and information streams. Block labels and model names are also shown, as well as convergence methods and their placement in the flowsheet. The purpose behind segregating the boiler into an economizer, evaporator, and superheater is to enable representation of the different heat transfer characteristics in these sections. The differences in heat transfer coefficients which prevail in sensible heating of liquids, latent heating during evaporation, and sensible heating of vapor are important in the estimation of boiler equipment size and cost. If only the heat requirement to the boiler was of interest, then the item could be modeled as one single heater.

The complete problem input files for the main simulation and the case study are presented in Appendix 1. The simulation is executed for a single component (water) system with physical properties calculated by a correlation (ASPEN physical property option SYSOP12), which determines water's thermodynamic properties as departures from an ideal gas model. Block parameters were set according to the specificatons in Figure 5.

3.2 Fortran Blocks and Unit Operations Design Specifications

The fraction of steam that is extracted from the turbine to be used for feedwater heating is calculated in fortran block X-CALC. This block samples enthalpies from the streams entering and leaving the feed water heater, and calculates the correct stream split.

The total flowrate for the cycle was determined by design specification block F-SPEC. This block samples the turbine work output rates and the pump power requirements and uses an iterative convergence technique (ASPEN's ONE-VAR, a secant-type of function solver) to vary the total mass flow until a net power output of 100 megawatts (MW) is achieved.

When this problem was studied, the PUMP model did not yet have the capability to calculate power requirement. Since these values are required by F-SPEC, fortran blocks P1WORK and P2WORK were implemented to do the calculation.

3.3 Process Simulation Results

The output from the process simulations are presented in the report files in Appendix 2. The history file shows the calculation sequence and all intermediate stream and block outlet values while the design specification and tear set are being converged. The report file shows flowsheet connectivity and stream calculation order, convergence results, the overall heat and material balance with related input, process data for all streams, and heat and material balance results for unit operation blocks.

3.3.1 Analysis

The heat rate of a plant is the input at the boiler system. The overall efficiency of the cycle is the quotient of the output work (100 MW) and the input heat. This data plus system flowrate is presented in Table 1 for the main and simplified cases, and also for a reference coal plant.

The similarity in heat rate between the ASPEN simulations and the reference plant show ASPEN's accuracy, with the variance attributable to differences in cycle parameters and the fact that the simulation assumed mechanical efficiencies of unity. The ASPEN system is capable of implementing equipment inefficiencies into a more detailed study.

The difference in thermal efficiency between the main simulation and the case study shows how reheat and feed water heat improve plant performance.

4 ECONOMIC EVALUATION

The ASPEN Cost Estimation and Economic Evaluation System was used to study plant capital requirements and project profitability for a solar power plant. The study generated :

- Purchased equipment costs,
- Material and labor installation costs,
- Site development and indirect project costs,
- Fixed and variable operating costs,
- A discounted cash flow analysis of project profitability, and
- An economic sensitivity study of the solar power plant concept, using ASPEN's DESIGN SPECIFICATION feature to vary plant capital investment.

Except for certain special equipment costs which could not be represented by currently available ASPEN models, all parts of the evaluation utilized ASPEN's capabilities.

4.1 Estimation of Capital Investment

Plant capital investment was calculated from values generated in the equipment COSTBLOCKs, the COST-SECTIONs, and a utility investment routine (UTILITY-INV). Associated costs for items such as land, site development, working capital and contingency were generated in section CAPITAL-INVE, using ASPEN factors applied to the total equipment cost, total installation materials cost and total installation labor hours generated in previous sections of the Economic Evaluation Subsystem.

4.1.1 Purchased Equipment Cost

ASPEN cost models were used to estimate purchased cost for the major pieces of equipment in the flowsheet. Factors used by the models were set to specify equipment number, type and material of construction. Heat exchanger and pump designs were generated based upon heat duties, flows, temperatures, pressures, and densities that were retrieved by the Economic Evaluation System from the process simulation. Values for the total installaton material cost factor (MAT) were derived from The ASPEN Project Thirteenth Quarterly Progress Report (6). Material of construction was assumed to be carbon steel for all equipment items except the condenser, which was designed with Admiralty alloy tubes to protect against corrosion from dissolved species (e.g. chlorine) in the cooling water. Overall heat transfer coefficients for the HEAT-EXCHANG blocks were calculated using solar heat fluxes reported by Zoschak and Wu (7). This was also the source of hot side (solar) temperatures. The hotwell volume was calculated by assuming a liquid residence time of 10 minutes and a void fraction of forty percent. The pump cost models were specified for high-speed (3550 rpm) horizontally-split-case, multi-stage pumps as named by Richardson (8).

4.1.2 Other Equipment Costs

Where an ASPEN model was not available (cooling towers and turbine-generator), a referenced value for purchased cost was inserted as an ADD-COST in a COST-SECTION.

The two turbines in the process flowsheet actually represent one turbine casing with an extraction point partway through the expansion. A 1975 purchased price of 8.85 million dollars (9) for a 125 MW combination turbine-generator was inserted in COST-SECTION TURB.

The plant cooling towers were included as an ADD-COST item in COST-SECTION COOLTWR. This amount is based upon a factor of 14 dollars per KW of capacity (10), in 1975 dollars.

A utility investment cost was calculated for the basic (without cooling towers) cooling water system supplying the condenser. This was done by referencing another plant's cooling water capital cost, and applying an exponential factor to the difference in system capacity. The reference value is in 1970 dollars and is for a 200 MW facility (11).

4.2 Plant Operating Cost

Operating cost was calculated using default ASPEN labor, material and local tax factors in section OPERATING-CO. The required number of operators for this plant was estimated to be thirty, but keyword NOP was specified to 15 because the ASPEN routine assumes a 24 hour production day, and a solar power plant could not operate for more than twelve hours per day. Product revenue was estimated by setting operating capacity to forty percent of the design capacity of 100 megawatts, to account for a twelve hour generating day at eighty percent of peak power capability and a 1979 selling price of 68 mills per kilowatt-hour (KWh) (12).

4.3 Profitability Analysis

Financial parameters were set to those of the utility in Table 2 (13).

The analysis calculates the selling price required to meet a DCFRR of twenty percent. This method is used with a design specification (AC-SPEC) to find the maximum amount available for expenditure on a solar collecting system. AC-SPEC uses convergence method ONE-VAR to vary the ADD-COST item in COST-SECTION SOLAR until the specified unit energy price is met. A competitive 1979 selling price of 68 mills per kilowatt hour of electricity was specified. The initial value given to the ADD-COST is the capital cost required for a coal fired plant's coal handling and pollution control equipment (14). It is interesting to insert this value in order to generate, on the first iteration of the cost convergence, the capital investment required for a 100 MW coal plant. This gives one an additional piece of data that can be compared to external values, in order check ASPEN's accuracy.

4.4 Results of Economic Analysis

The output from the economic evaluation is located in Appendix 3.

The value of 851 $/KW calculated during iteration 1 of the simulation is the estimated capital cost for a coal fired power plant. This is only 13 percent different than the value of 750 $/KW mentioned in section 1.3.

Figure 7 shows additional (solar) and total capital cost plotted versus selling price.

This shows how much capital is available for expenditure on solar collection equipment at any electricity selling price. This information is useful in evaluating present and future economic feasability. One can compare the available amount to estimated collector cost to determine how close the venture is to feasibility.

Assuming 7000 heliostats of 40 square meters each (280000 sq.m.) gives a collector cost of 11.8 $/sq.m. at a selling price of 68 mills per KWh. The D.O.E.'s estimate for lowest possible collector cost at mass produced outputs is 75 $/sq.m. (15). To pay for this, the selling price would have to be 136 mills per KW, according to Figure 7. This value differs by 24 percent from D.O.E. estimates of 179 mills per KWh (16). This is well within the accuracy of ASPEN's equipment costing routines.

5 CONCLUSIONS

The results from both the process simulation and economic evaluation of the problem compare well to data from other studies. This vouches for ASPEN's credibility as a process simulator and economic evaluation system, and tends to support the message that it states concerning solar power generation : Solar currently is not economically attractive.

	BASE CASE	SIMPLE CASE	COAL PLANT
HEAT RATE (W) (Q)	2.49×10^8	2.78×10^8	2.82×10^8
EFFICIENCY $\left(\frac{Q}{10^8 \text{ WATTS}}\right)$	.40	.36	.35
FLOW $\left(\frac{\text{lbmole}}{\text{hr}}\right)$	$.422 \times 10^5$	$.387 \times 10^5$	—

TABLE 1: Process Simulation Results.

TABLE 2

FINANCIAL ANALYSIS PARAMETERS
FOR THE BASE CASES

Sponsor: A large investor-owned firm. Capable of financing project and claiming tax credits as they occur.

Dollar Method: Then-Current Dollars.

Dollar Date for Base Year Estimate, 1979

Schedules	Time, Years	
Construction	4	
Operations	20	
Retirement	(Instant)	
Construction Expenditure Rate (% year)	9/-4,25/3,36/-2,30/-1	
Plant Start-up Efficiences (% each year)	50/1,90/2,100/3, etc.	
Type of Firm	UTILITY	PRIVATE
Discount Rates (% per year)		
Debt Financing	10	10
Equity Financing	17	17
Financial Structure		
Debt (% total)	65	40
Equity (% total)	35	60
Escalation Rates (% per year)		
General Rate	7	7
Depreciation Methods		
Tax Life (years)	15	15
Method	SYD	SYD
Tax Rates and Schedules		
Effective Income Tax Rate	0.50	0.50
Federal Income Tax Rate	0.46	0.46
Effective Investment Tax Credit Rate (ITC), %	9%	9%
ITC Claim Schedule & year, % of investment	Year of Occurence	
Income and Other Tax Credit	Year of Occurence	
Capital Factor	.081	.115

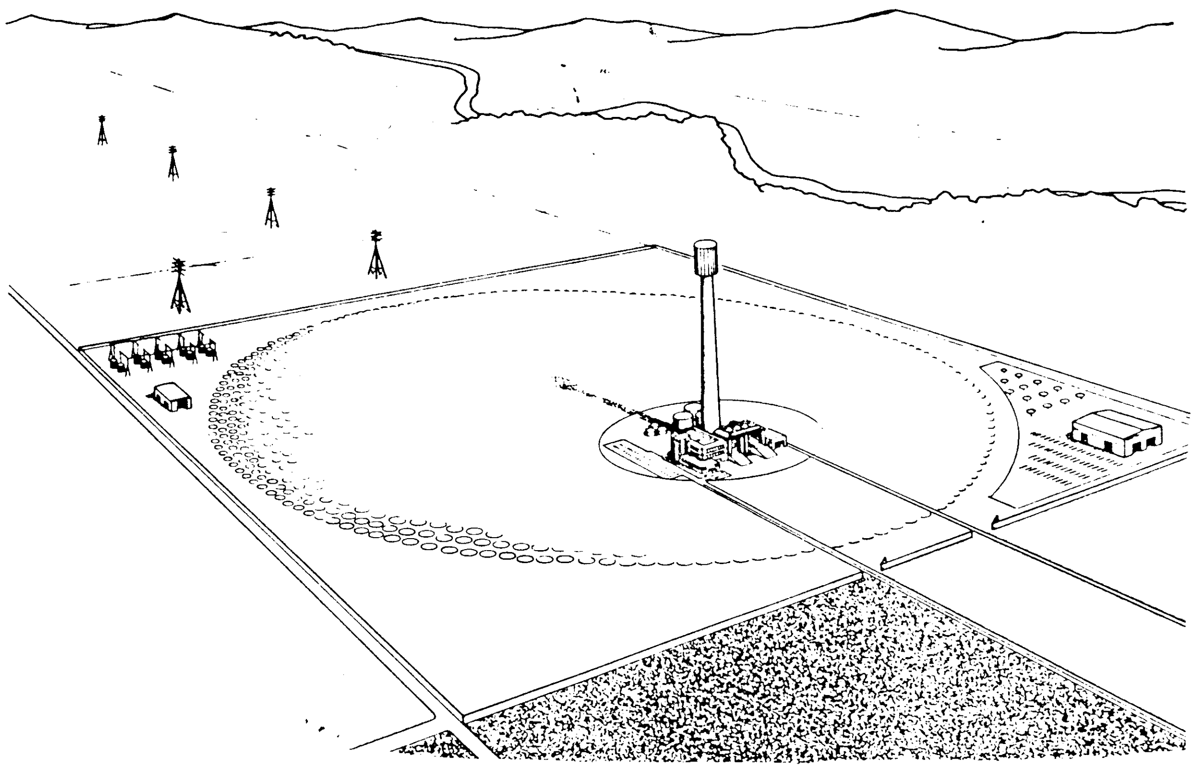


Figure 1: Central Receiver Solar Power PLant

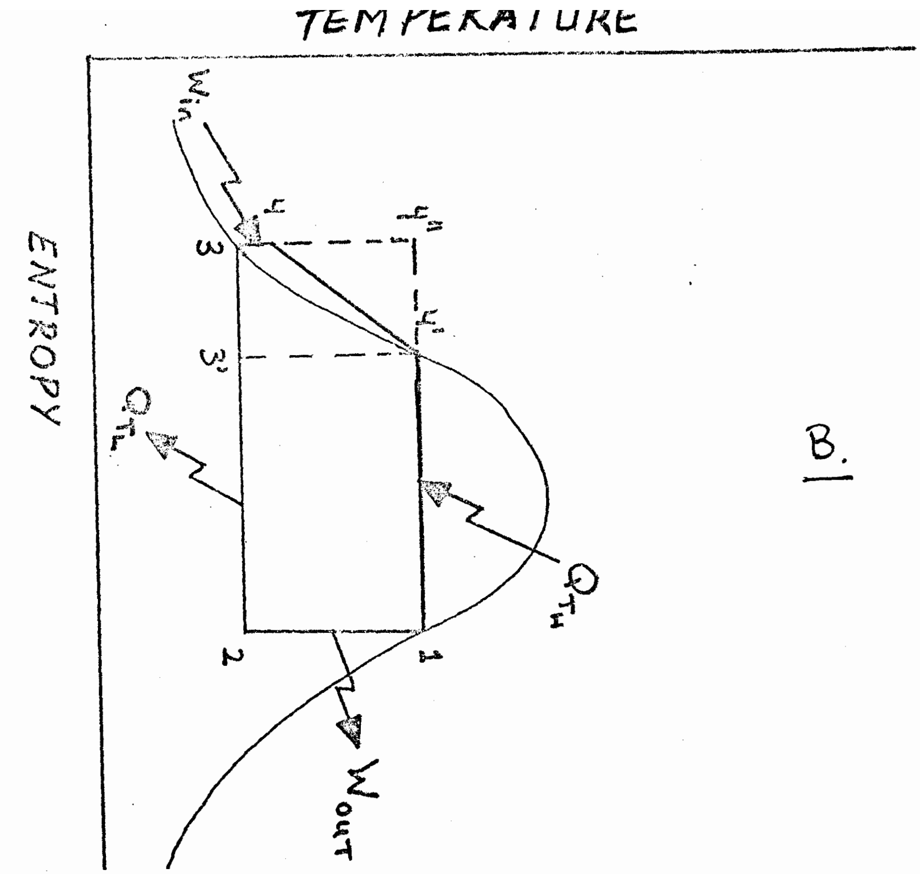
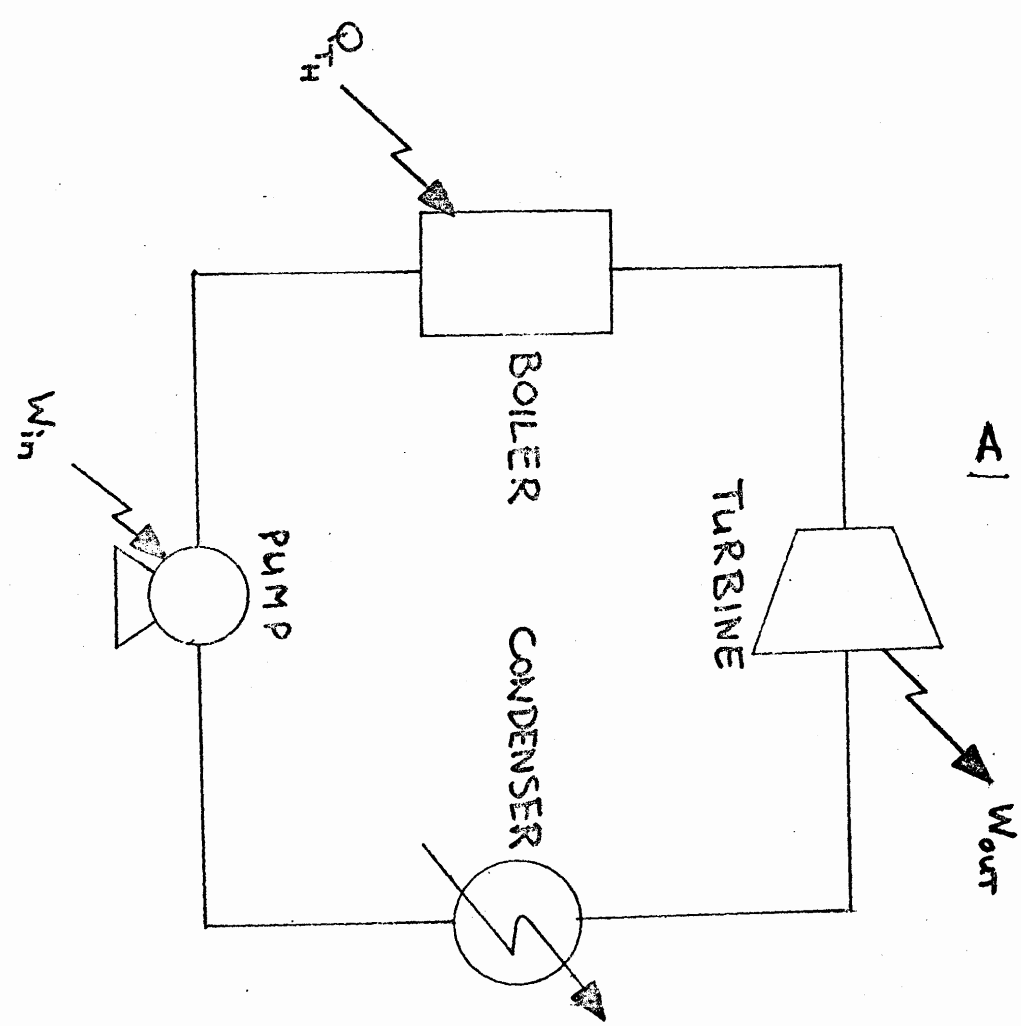


FIGURE 2 : RANKINE + CARNOT CYCLES



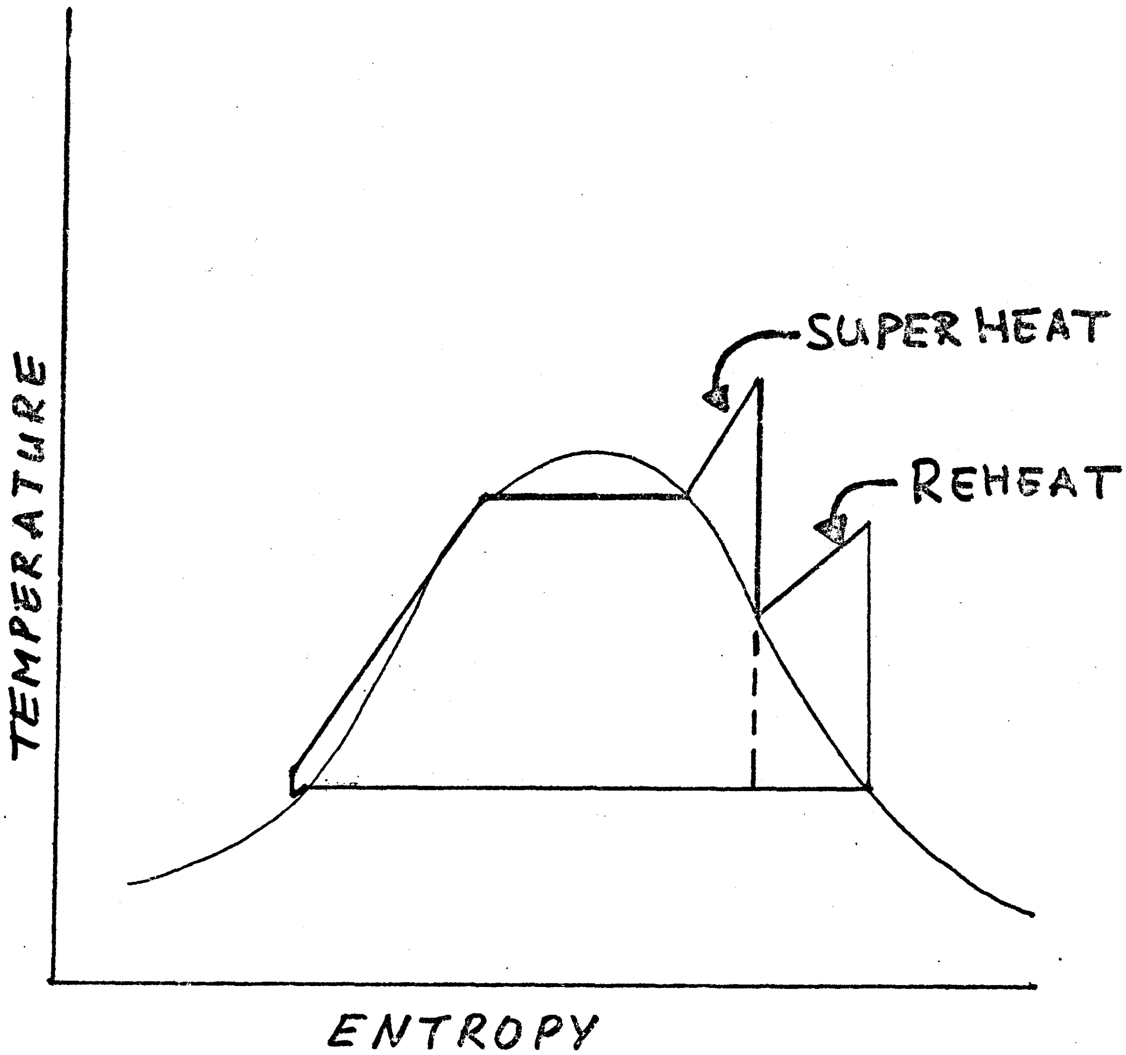


FIGURE 3: SUPERHEAT + REHEAT

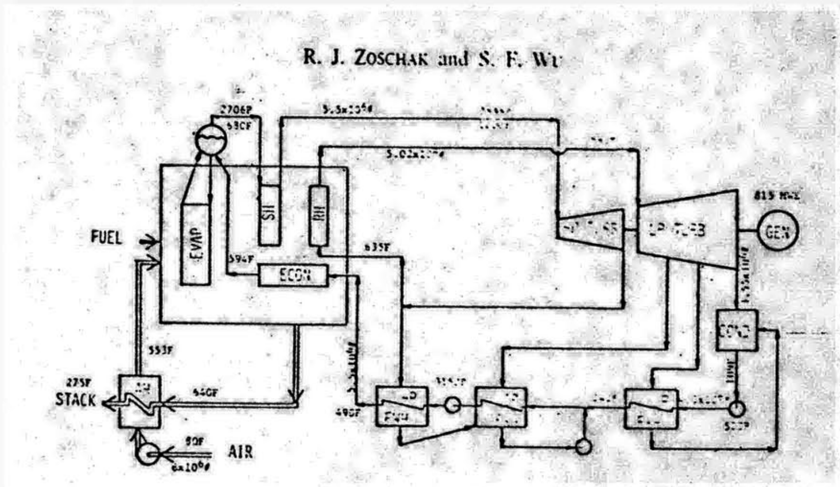


Figure 4: Commercial Cycle Process Flowsheet

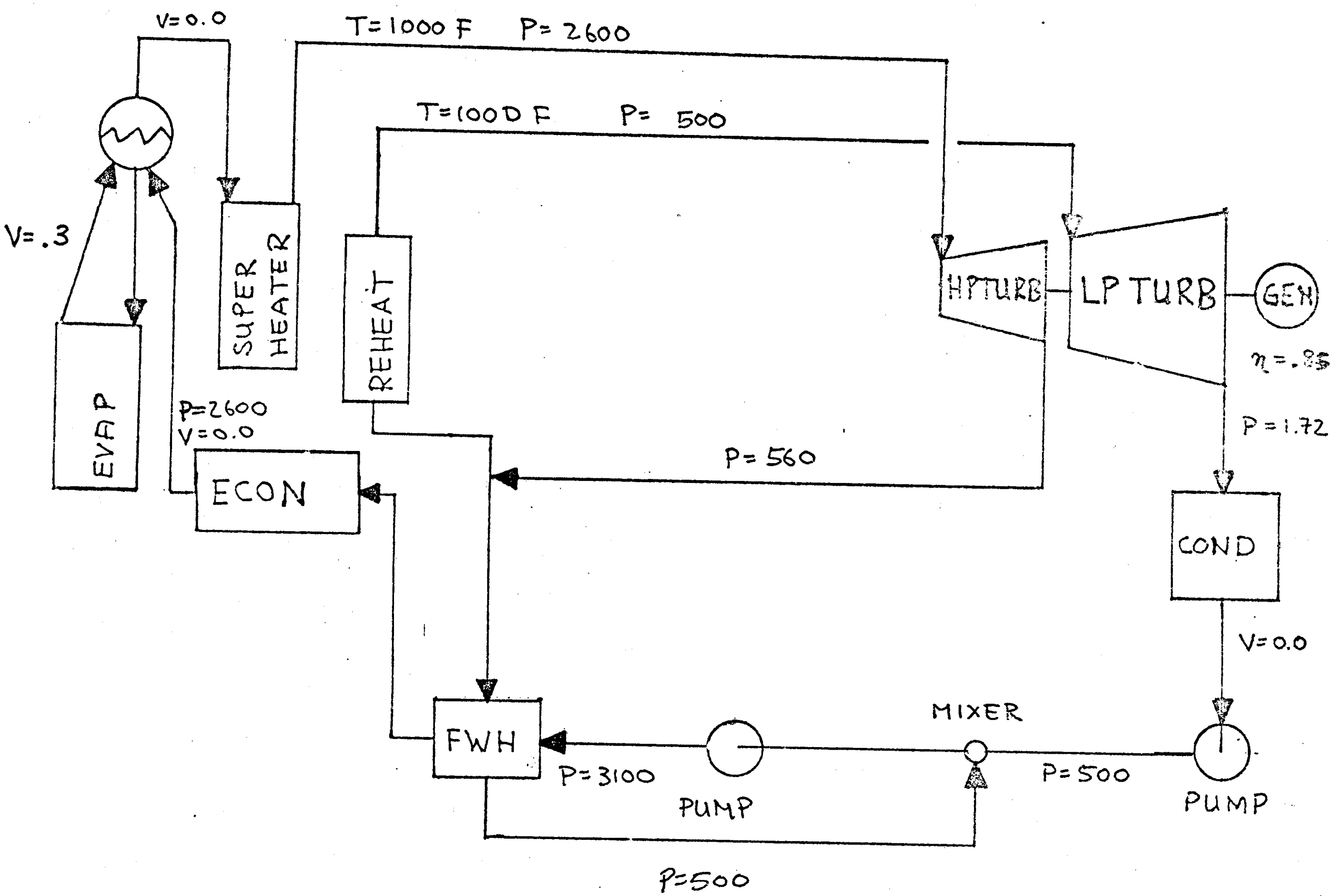


Figure 5: Simulated Cycle Process Flowsheet

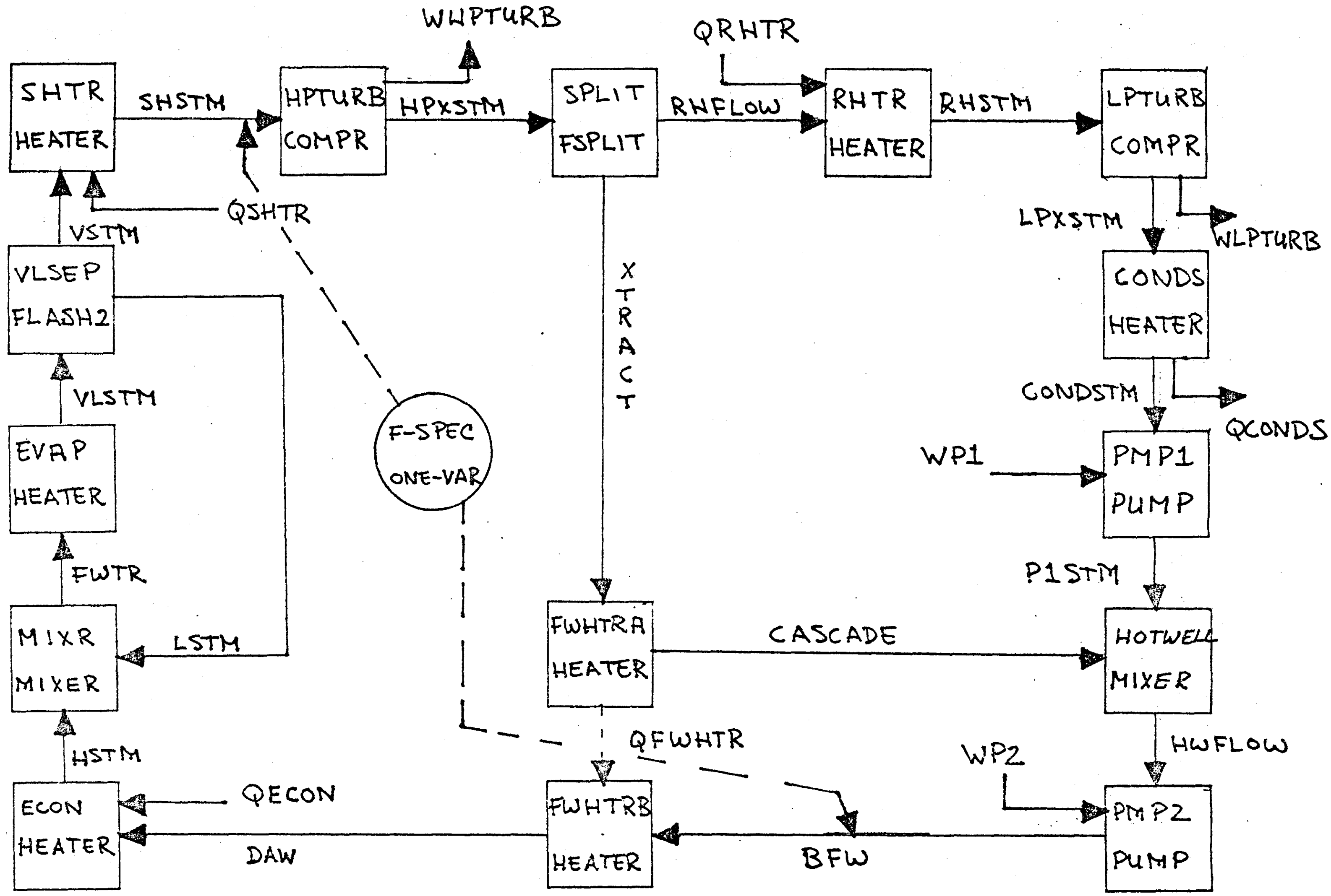


Figure 6: Flowsheet Block Diagram

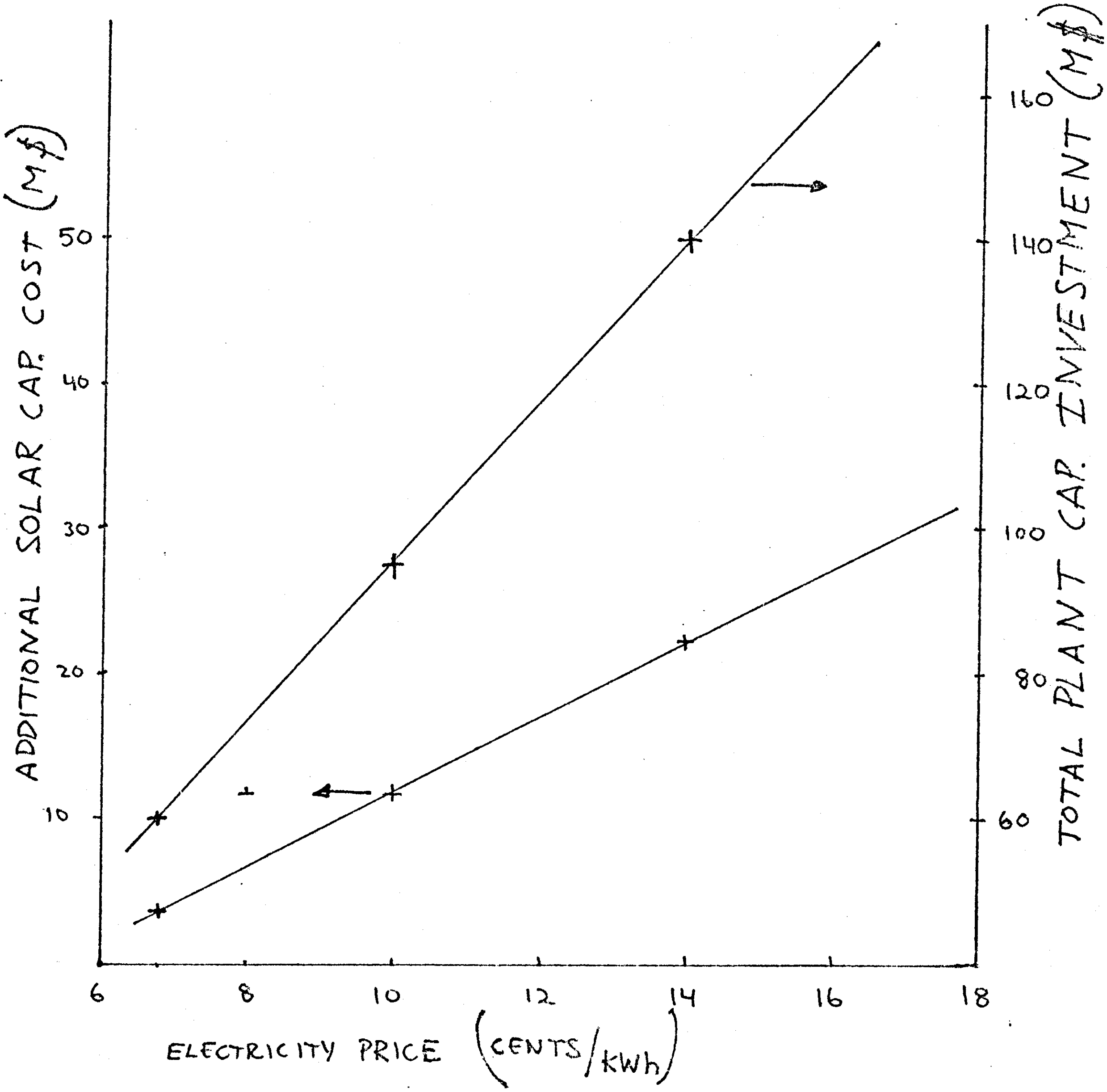


Figure 7: INVESTMENT VS. PRICE.

APPENDIX 1 : INPUT LANGUAGE

```
NEW

;
;  APPENDIX 1 : -------------- BASE CASE -----------------
;                PROCESS SIMULATION AND ECONOMIC EVALUATION
;                OF A 100 MW SOLAR POWER PLANT.
;               ------------------------------------------
;
TITLE  'STEAM POWER CYCLE'
DESCRIPTION 'PROCESS SIMULATION AND ECONOMIC EVALUATION FOR SOLAR POWER PLANT'
IN-UNITS ENG
OUT-UNITS ENG
;               -------------------------------------------
;                     SECTION 1 : PROCESS SIMULATION
;               -------------------------------------------
COMPONENTS H2O WATER
FORMULA H2O H2O
SIM-OPTIONS   HMB-RESULTS=2 SIZE-RESULTS=2      ; CALCULATES STREAM DENSITIES
;                                                 FOR PUMP WORK FORTRAN BLOCKS
;
PROPERTIES MYSYSOP GLOBAL               ; IMPROVED ENTHALPY DEPARTURE CORRELATION.
;                                         CALCULATES WATER PHYSICAL PROPERTIES
PROP-OPTIONS MYSYSOP SYSOP12 PHILMX PHILMX00 / PHIVMX MYPHIVMX
MP-ROUTE MYPHIVMX PHIVMX 1 *
;
DEF-STREAMS     HEAT  QECON QEVAP QSHTR QRHTR QCONDS QFWHTR    &
                /WORK   WHPTURB WLPTURB WP1 WP2
TEAR BFW / LSTM
HISTORY
   MSG-LEVEL STREAMS=4 PROPERTIES=2 SIM=4
FLOWSHEET
    ECON       IN=DAW                      OUT=HSTM        QECON
    MIXR       IN=LSTM    HSTM             OUT=FWTR
    EVAP       IN=FWTR                     OUT=VLSTM       QEVAP
    VLSEP      IN=VLSTM                    OUT=VSTM        LSTM
    SHTR       IN=VSTM                     OUT=SHSTM       QSHTR
    HPTURB     IN=SHSTM                    OUT=HPXSTM      WHPTURB
    SPLIT      IN=HPXSTM                   OUT=RHFLOW      XTRACT
    RHTR       IN=RHFLOW                   OUT=RHSTM       QRHTR
    LPTURB     IN=RHSTM                    OUT=LPXSTM      WLPTURB
    CONDS      IN=LPXSTM                   OUT=CONDSTM     QCONDS
    PMP1       IN=CONDSTM                  OUT=P1STM       WP1
    HOTWELL    IN=P1STM     CASCADE        OUT=HWFLOW
    PMP2       IN=HWFLOW                   OUT=BFW         WP2
    FWHTRA     IN=XTRACT    QFWHTR         OUT=CASCADE
    FWHTRB     IN=BFW                      OUT=DAW         QFWHTR
;
;------------------- STREAM INITIALIZATION --------------------
STREAM BFW PRES=3100 TEMP=220.
         MASS-FLOW H2O 100000.
STREAM LSTM PRES=2600 V=1.0
         MASS-FLOW H2O 300000.
;
;--------------------UNIT OPERATIONS BLOCKS-------------------
BLOCK    ECON   HEATER
```

```
   PARAM   PRES=2600  V=0.0
;
BLOCK EVAP HEATER
   PARAM  PRES=2600.  V=.25
;
BLOCK  VLSEP  FLASH2
;
BLOCK MIXR  MIXER
   PARAM  PRES=2600
;
BLOCK SHTR HEATER
   PARAM  TEMP=1000  PRES=2500.
;
BLOCK    HPTURB    COMPR
    PARAM    3   580   ES=.87
;
BLOCK    SPLIT    FSPLIT
   FRAC RHFLOW .7 / XTRACT 0.3
;
BLOCK RHTR HEATER
    PARAM   TEMP=1000.   PRES=560.  NPK=1  KPH=1
;
BLOCK      LPTURB    COMPR
     PARAM    3   1.72       ES=.85
;
BLOCK     CONDS   HEATER
    PARAM  PRES=1.718   V=0.
;
BLOCK     PMP1   PUMP
    PARAM  500   1
;
BLOCK    HOTWELL    MIXER
    PARAM    PRES=500.
;
BLOCK    PMP2   PUMP
    PARAM   3100    1
;
BLOCK    FWHTRB    HEATER
     PARAM    TEMP=500.  PRES=3000.   NPK=1   KPH=2
;
BLOCK    FWHTRA   HEATER
    PARAM    PRES=500.       V=0.0
;
;
REPORT STREAMS BLOCKS FLOWSHEET
;
;-------------------- FORTRAN BLOCKS --------------------
FORTRAN   X-CALC               ;CALCULATES NEW SPLIT FRACTION.
    DEFINE HAO  STREAM-VAR STREAM=CASCADE VARIABLE=MOLE-ENTH
    DEFINE HAI  STREAM-VAR STREAM=XTRACT  VARIABLE=MOLE-ENTH
    DEFINE HBO  STREAM-VAR STREAM=DAW     VARIABLE=MOLE-ENTH
    DEFINE HBI  STREAM-VAR STREAM=BFW     VARIABLE=MOLE-ENTH
    DEFINE X1 BLOCK-VAR  BLOCK=SPLIT SENTENCE=FRAC VARIABLE=FRAC ID1=XTRACT
    DEFINE X2 BLOCK-VAR  BLOCK=SPLIT SENTENCE=FRAC VARIABLE=FRAC ID1=RHFLOW
F       WRITE(NHSTRY,*) HAO,HAI,HBO,HBI
```

```
F        X1 = (HBO-HBI)/(HAI-HAO)
F        X2 = 1-X1
F        WRITE(NHSTRY,*) X1,X2
    EXECUTE AFTER PMP2
;
FORTRAN P1WORK                          ;CALCULATES PUMP WORK
     IN-UNITS SI
    DEFINE P1I STREAM-VAR STREAM=CONDSTM VARIABLE=PRES
    DEFINE P1O STREAM-VAR STREAM=P1STM VARIABLE=PRES
    DEFINE F1 STREAM-VAR STREAM=CONDSTM VARIABLE=MASS-FLOW
    DEFINE D1 STREAM-VAR STREAM=CONDSTM VARIABLE=MASS-DENSITY
    VECTOR-DEF WIII STREAM STREAM=WP1
F        WIII(1) = (P1O-P1I)*F1/D1
F        WRITE(NHSTRY,*) P1O,P1I,F1,D1
F        WRITE(NHSTRY,*) WIII(1)
    EXECUTE AFTER PMP1
;
FORTRAN P2WORK                            ;CALCULATES PUMP WORK
    IN-UNITS SI
    DEFINE P2I STREAM-VAR STREAM=HWFLOW VARIABLE=PRES
    DEFINE P2O STREAM-VAR STREAM=BFW VARIABLE=PRES
    DEFINE F2 STREAM-VAR STREAM=HWFLOW VARIABLE=MASS-FLOW
    DEFINE D2 STREAM-VAR STREAM=HWFLOW VARIABLE=MASS-DENSITY
    VECTOR-DEF WIV STREAM STREAM=WP2
F        WIV(1) = (P2O-P2I)*F2/D2
F        WRITE(NHSTRY,*) P2O,P2I,F2,D2
F        WRITE(NHSTRY,*) WIV(1)
    EXECUTE AFTER PMP2
;
;--------DESIGN SPECIFICATION TO CALC. TOTAL SYSTEM FLOWRATE.-----
DES-SPEC  F-SPEC                        ;OPTIMIZES TOTAL FLOW.
    VECTOR-DEF WI STREAM STREAM=WHPTURB
    VECTOR-DEF WII STREAM STREAM=WLPTURB
    VECTOR-DEF WIII STREAM STREAM=WP1
    VECTOR-DEF WIV STREAM STREAM=WP2
    SPEC  'DABS( WI(1) + WII(1)  - WIII(1) - WIV(1) )'  TO 1.D+8
    TOL-SPEC   100000.
    VARY  STREAM-VAR STREAM=SHSTM VARIABLE=MASS-FLOW
    LIMITS   1.D+3   1.D+9
;
;        ------------------------------------
;        SECTION 2 : ECONOMIC EVALUATION
;        ------------------------------------
;
;--------------------- EQUIPMENT COSTING ------------------
CBLOCK PMP1COST COST-PUMP
    INST-FACTORS  MAT=1.3
    BLOCK-OPTIONS SIM-LEVEL=4
    HMB-REFERENCE BLK=PMP1
    PARAM  NPMP=1 NSB=1 PTYP=5 MTYP=2 SRSY=3 MAT=1 &
           SFCT=1.0 CFCT=1
;
CBLOCK PMP2COST COST-PUMP
    INST-FACTORS  MAT=1.3
    BLOCK-OPTIONS  SIM-LEVEL=4
```

```
    HMB-REFERENCE BLK=PMP2
    PARAM  NPMP=1 NSB=1 PTYP=5 MTYP=2 SRSY=3 MAT=1 &
           SFCT=1.0 CFCT=1
;
CBLOCK ECONCOST  HEAT-EXCHANG
    INST-FACTORS  MAT=.912
    BLOCK-OPTIONS  SIM-LEVEL=4
    HMB-REFERENCE   BLK=ECON
    PARAM  TYPE=1 NEQ=1 NSB=0 SMAT=1 TMAT=1 SFCT=1 &
           CFCT=1 SPRS=1[PSI] TPRS=3000  FDT=1 FPR=1
    SIZE-INPUT   U=600  TI2 = 1100  TO2 =1100
;
CBLOCK EVAPCOST  HEAT-EXCHANG
    INST-FACTORS MAT=.934
    BLOCK-OPTIONS  SIM-LEVEL=4
    HMB-REFERENCE  BLK=EVAP
    PARAM  TYPE=1 NEQ=1 NSB=0 SMAT=1 TMAT=1 SFCT=1 &
           CFCT=1 SPRS=1[PSI] TPRS=3000  FDT=1 FPR=1
    SIZE-INPUT  U=800  TI2 = 900  TO2 = 900
;
CBLOCK SHCOST HEAT-EXCHANG
    INST-FACTORS  MAT=.981
    BLOCK-OPTIONS SIM-LEVEL=4
    HMB-REFERENCE  BLK=SHTR
    PARAM  TYPE=1 NEQ=1 NSB=0 SMAT=1 TMAT=1 SFCT=1 &
           CFCT=1 SPRS=1[PSI] TPRS=3000  FDT=1 FPR=1
    SIZE-INPUT   U=240  TI2 = 1290.  TO2 = 1290.
;
CBLOCK RHCOST HEAT-EXCHANG
    INST-FACTORS  MAT=.971
    BLOCK-OPTIONS SIM-LEVEL=4
    HMB-REFERENCE  BLK=RHTR
    PARAM  TYPE=1 NEQ=1 NSB=0 SMAT=1 TMAT=1 SFCT=1 &
           CFCT=1 SPRS=1[PSI] TPRS=800  FDT=1 FPR=1
    SIZE-INPUT    U=100  TI2 = 1290  TO2 = 1290
;
; COSTING OF PROCESS HEATERS
;
CBLOCK FWHTCOST HEAT-EXCHANG
    INST-FACTORS  MAT=.949
    BLOCK-OPTIONS SIM-LEVEL=4
    HMB-REFERENCE  FWHTRA FWHTRB
    PARAM   TYPE=1 NEQ=1 NSB=0 SMAT=1 TMAT=1 SFCT=1 CFCT=1 SPRS=600 &
            TPRS=3600  FDT=1 FPR=1
    SIZE-INPUT  U=600
;
CBLOCK CONDCOST HEAT-EXCHANG
    INST-FACTORS  MAT=.92
    BLOCK-OPTIONS  SIM-LEVEL=4
    HMB-REFERENC    CONDS
    PARAM   TYPE=1 NEQ=1 NSB=0 SMAT=1 TMAT=15 SFCT=1 CFCT=1 SPRS=15  &
             TPRS=15  FDT=1 FPR=1
    SIZE-INPUT  U= 600 NSPS=1  NTPS=2  ; TI2=80 TO2=110
    UTILITY   WATER=CONDWTR
;
```

```
UTILITY CONDWTR WATER 2
    PARAM  TEMP=80  RTMP=110
;
; COSTING OF HOTWELL
;
CBLOCK HWCOST COST-VERVSSL
    INST-FACTORS  MAT=.766
    BLOCK-OPTIONS  SIM-LEVEL=4
    PARAM NVS=1 NSB=0 MAT=1  SFCT=1 CFCT=1
    SIZE-INPUT  DIA=10[FT]  VOL=2200.[CUFT]  PRES=650.
;
;
; --------------------PROFITABILITY ANALYSIS-------------
ECONOMICS
    EXECUTION START=1 END=3
    BLOCK-OPTION    4
    PARAM  NTRAIN=1 AVAL=.90 CAPC=1
    COST-INDEX  PLANT=231. PCOD=1 ;EQUIP=1 LABOR=1 INSTAL=1 CHEM=1
;
COST-SECTION COOLTWR                         ; COOLING TOWER  COST
     INST-FACTORS  LAB=.004
    ADD-COST COST=.55D+6  INDX=182.  CODE =1
;
COST-SECTION TURB
    INST-FACTORS LAB=.004  MAT=1.27
    ADD-COST  COST=8.85D+6  INDX=182.0  CODE=1
COST-SECTION SOLAR                   ;SOLAR COLLECTOR OR COAL HANDLING COST
    BLOCKS ALL
    INST-FACTORS LAB=.004
    ADD-COST  COST=.93D+7   INDX=231.0  CODE=1
;
UTILITY-INVE WATER  FACTOR=1
    INVESTMENT  BCST=6.D+5  BCAP=8.819D+7 [KG/SEC]  EXP= .60  &
          INDX=123.   CODE=1   MIN=.1D+7   MAX=.1D+9   LFCT=.02
;
;
CAPITAL-INVE
    GEN-FACILITY RMD=0 PRD=0 STRL=0 BLGM=.05 BLGL=.02 DISM=.04 DISL=.01
    SITE-DEVELOP  MFCT=.01 LFCT=.02
    INDIRECT-FAC  OWNR=.075  FIELD=.12  CONT=.075 PRMT=.075
    FREIGHT-CHAR FACT=.02
    CONTINGENCY PROJ=.10  PROC=.20
    LAND   FACTOR=.02
    WORKING-CAPI  METH=1  FACTOR=.10
    STARTUP-COST  METH=1 FACTOR=.06
    ROYALTY    FACTOR=0
    CATALYST  AMNT=0
    LABOR PROD=1.4  RATE=13.20
;
PRODUCT POWER
    FLOW-RATE  MASS-FLOW=50000 [KG/SEC] DENSITY=.00001 ;REALLY KW.
    PRICE  PRICE=.189D-4 [$/KG]   INDX=231.0   CODE=1
;
OPERATING-CO
    CAPACITY  1  *  *
```

```
    LABOR  RATE=13.20  NOP=20  EFF=1. SPRV=.2 GEN=.60 FRIN=.4 MFCT=.036
    MATERIAL  MFCT=.024 SFCT=.1
    LOCAL-RATE  TAX=.02 INS=.0075
    CATALYST  RATE=0 COST=0
    WASTE RATE=0  COST=0
    OTHERS   FACT=.03
;
PROFITABILIT
    SCHEDULE  BEGN=0 CNST=4 OPER=20
    DEPRECIATION METH=2 LIFE=15 SALV=0
    TAX-RATE  EFF=.5 FED=.46 STATE=.0774 CRDT=.10
    DEBT  FRAC=.65   INTR=.20
    ANALYSIS   METH=2  RRTN=.20
    ESCALATION  GEN=.07  LAB=.07
    CAPITAL-PROF 1 .09/ 2 .25/ 3 .36/ 4 .30
    CAPACITY-PRO 1 .5/ 2 .9/ 3 1.
;
;--------DESIGN SPECIFICATION TO CALC. SOLAR CAPITAL COST-----
DES-SPEC  AC-SPEC                          ; CALCULATES SOLAR CAPITAL INVESTMENT
    IN-UNITS SI
    DEFINE PC PROFITABILIT  SENTENCE=RESULTS VAR=PRIC
    DEFINE PLC PROFITABILIT SENTENCE=RESULTS  VAR=LPRC
    DEFINE PRC PROFITABILIT SENTENCE=RESULTS  VAR =NPRC
F       WRITE(NHSTRY,*) PC,PLC,PRC
    SPEC PC TO .189D-4        ; PRICE IS .068 $ PER KWH
    TOL-SPEC  .1D-6
    VARY COST-SEC-VAR  SECTION=SOLAR SENTENCE=ADD-COST VAR=COST
    LIMITS  1.D+5  1.D+9
;
SEQUENCE MAIN  CONV1  FWHTRB ECON MIXR EVAP VLSEP SHTR CONV2 HPTURB &
  SPLIT FWHTRA RHTR LPTURB CONDS PMP1 HOTWELL  PMP2 (RETURN CONV2) &
  (RETURN CONV1) PMP1COST PMP2COST ECONCOST EVAPCOST SHCOST RHCOST FWHTCOST  &
  CONDCOST HWCOST  CONV3  ECONOMIC (RETURN CONV3)
;
CONVERGENCE CONV3 ONE-VAR
    BLOCK-OPTIONS SIM-LEVEL=4
    SPEC AC-SPEC
CONVERGENCE  CONV2 ONE-VAR
    SPEC F-SPEC
CONVERGENCE CONV1 WEGSTEIN
  TEAR BFW / LSTM
```

```
NEW
;
; APPENDIX 1 :  ---------SIMPLE RANKINE CYCLE ----------
;               SIMULATED IN ORDER TO COMPARE CYCLE
;               EFFICIENCIES.
;              --------------------------------------
;
TITLE 'SIMPLIFIED STEAM CYCLE'
DESCRIPTION 'RANKINE CYCLE WITHOUT REHEAT, OR FEEDWATER HEAT.'
IN-UNITS ENG
OUT-UNITS ENG
COMPONENTS H2O WATER
FORMULA H2O H2O
SIM-OPTIONS HMB-RESULTS=2
;
PROPERTIES MYSYSOP GLOBAL            ; IMPROVED ENTHALPY DEPARTURE CORRELATION.
PROP-OPTIONS MYSYSOP SYSOP12 PHILMX PHILMX00 / PHIVMX MYPHIVMX
MP-ROUTE MYPHIVMX PHIVMX 1 *
;
DEF-STREAMS    HEAT  QECON QEVAP QSHTR  QCONDS    &
               /WORK   WHPTURB WP1
TEAR DAW / LSTM
HISTORY
    MSG-LEVEL  STREAMS=4  PROPERTIES=2 SIM=4
FLOWSHEET
    ECON      IN=DAW                 OUT=HSTM       QECON
    MIXR      IN=LSTM   HSTM         OUT=FWTR
    EVAP      IN=FWTR                OUT=VLSTM      QEVAP
    VLSEP     IN=VLSTM               OUT=VSTM       LSTM
    SHTR      IN=VSTM                OUT=SHSTM      QSHTR
    HPTURB    IN=SHSTM               OUT=HPXSTM     WHPTURB
    CONDS     IN=HPXSTM              OUT=CONDSTM    QCONDS
    PMP1      IN=CONDSTM             OUT=DAW      WP1
;
STREAM DAW PRES=3100 TEMP=150.
         MASS-FLOW H2O 10000.
STREAM LSTM PRES= 2600 V=1.0
    MASS-FLOW  H2O 30000.
;
BLOCK    ECON   HEATER
    PARAM   PRES=2600  V=0.0
;
BLOCK EVAP HEATER
    PARAM  PRES=2600.  V=.25
;
BLOCK  VLSEP  FLASH2
;
BLOCK MIXR  MIXER
    PARAM  PRES=2600
;
BLOCK SHTR HEATER
    PARAM  TEMP=1000  PRES=2500.
;
BLOCK    HPTURB    COMPR
     PARAM    3   1.72   ES=.86
```

```
;
BLOCK      CONDS    HEATER
     PARAM   PRES=1.718    V=0.
;
BLOCK      PMP1    PUMP
     PARAM   3100    1
;
FORTRAN P1WORK                       ;CALCULATES PUMP WORK
     IN-UNITS SI
    DEFINE P1I STREAM-VAR STREAM=CONDSTM VARIABLE=PRES
    DEFINE P1O STREAM-VAR STREAM=DAW VARIABLE=PRES
    DEFINE F1 STREAM-VAR STREAM=CONDSTM VARIABLE=MASS-FLOW
    DEFINE D1 STREAM-VAR STREAM=CONDSTM VARIABLE=MASS-DENSITY
    VECTOR-DEF WIII STREAM STREAM=WP1
F        WIII(1) = (P1O-P1I)*F1/D1
F        WRITE(NHSTRY,*) P1O,P1I,F1,D1
F        WRITE(NHSTRY,*) WIII(1)
    EXECUTE AFTER PMP1
;
DES-SPEC  F-SPEC                     ;OPTIMIZES TOTAL FLOW.
    VECTOR-DEF WI STREAM STREAM=WHPTURB
    VECTOR-DEF WIII STREAM STREAM=WP1
    SPEC  'DABS( WI(1)    - WIII(1)   )'  TO 1.D+8
    TOL-SPEC    100000.
    VARY  STREAM-VAR STREAM=SHSTM VARIABLE=MASS-FLOW
    LIMITS    1.D+3    1.D+9
;
SEQUENCE MAIN CONV1 ECON MIXR EVAP VLSEP SHTR CONV2 HPTURB &
   CONDS PMP1 (RETURN CONV2) (RETURN CONV1)
;
CONVERGENCE CONV2 ONE-VAR
    SPEC F-SPEC
CONVERGENCE CONV1 WEGSTEIN
    TEAR DAW / LSTM
```

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STEAM POWER CYCLE

DESCRIPTION

PROCESS SIMULATION AND ECONOMIC EVALUATION FOR SOLAR POWER PLANT

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STEAM POWER CYCLE

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ECONOMIC EVALUATION SECTION

APPENDIX 2: Process Simulation Results

```
 WHPTURB   HPTURB     ----         RHFLOW    SPLIT     RHTR
 XTRACT    SPLIT      FWHTRA       RHSTM     RHTR      LPTURB
 QRHTR     RHTR       ----         LPXSTM    LPTURB    CONDS
 WLPTURB   LPTURB     ----         CONDSTM   CONDS     PMP1
 QCONDS    CONDS      ----         P1STM     PMP1      HOTWELL
 WP1       PMP1       ----         HWFLOW    HOTWELL   PMP2
 BFW       PMP2       FWHTRB       WP2       PMP2      ----
 CASCADE   FWHTRA     HOTWELL      DAW       FWHTRB    ECON
 QFWHTR    FWHTRB     FWHTRA

FLOWSHEET CONNECTIVITY BY BLOCKS

  BLOCK        INLETS                      OUTLETS
 ECON         DAW                         HSTM QECON
 MIXR         LSTM HSTM                   FWTR
 EVAP         FWTR                        VLSTM QEVAP
 VLSEP        VLSTM                       VSTM LSTM
 SHTR         VSTM                        SHSTM QSHTR
 HPTURB       SHSTM                       HPXSTM WHPTURB
 SPLIT        HPXSTM                      RHFLOW XTRACT
 RHTR         RHFLOW                      RHSTM QRHTR
 LPTURB       RHSTM                       LPXSTM WLPTURB
 CONDS        LPXSTM                      CONDSTM QCONDS
 PMP1         CONDSTM                     P1STM WP1
 HOTWELL      P1STM CASCADE               HWFLOW
 PMP2         HWFLOW                      BFW WP2
 FWHTRA       XTRACT QFWHTR               CASCADE
 FWHTRB       BFW                         DAW QFWHTR

DESIGN-SPEC:  F-SPEC

  SAMPLED VARIABLES:
    WI       IS STREAM         IN STREAM WHPTURB  SUBSTREAM
    WII      IS STREAM         IN STREAM WLPTURB  SUBSTREAM
    WIII     IS STREAM         IN STREAM WP1      SUBSTREAM
    WIV      IS STREAM         IN STREAM WP2      SUBSTREAM

  SPECIFICATION:
    MAKE DABS( WI(1) + WII(1) - WIII(1) - WIV(1) ) APPROACH 1.D+8
    WITHIN    100,000.

  MANIPULATED VARIABLES:
    VARY THE TOTAL MASSFLOW  IN STREAM SHSTM    SUBSTREAM MIXED
    BETWEEN      1,000.00       AND         1.000000+09 LB/HR
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                                   STEAM POWER CYCLE
                                    FLOWSHEET SECTION

DESIGN-SPEC:  AC-SPEC

  SAMPLED VARIABLES:
    PC       IS UNIT-PRICE     IN BLOCK
    PLC      IS UNIT-PRICE     IN BLOCK
    PRC      IS UNIT-PRICE     IN BLOCK
```

```
   FORTRAN STATEMENTS:
          WRITE(NHSTRY,*) PC,PLC,PRC

   SPECIFICATION:
     MAKE PC APPROACH .189D-4
     WITHIN          0.100000-06

   MANIPULATED VARIABLES:
     VARY THE FISCAL          IN BLOCK
     BETWEEN    100,000.         AND          0.100000+10 M-DOLL

 CONVERGENCE BLOCK:  CONV3
       SPECS: AC-SPEC
       MAXIT=   30 STEP-SIZE=    0.010 MAX-STEP=    0.100
     CONV3     (SECANT   ) ITER=  3    *** CONVERGED ***
                                            X              OLD X            ERROR
 FISCAL            M-DOLL          0.3299713D+07   0.3299713D+07   0.0

 CONVERGENCE BLOCK:  CONV2
       SPECS: F-SPEC
       MAXIT=   30 STEP-SIZE=    0.000 MAX-STEP=    0.100
     CONV2     (SECANT   ) ITER= 18    *** CONVERGED ***
                                            X              OLD X            ERROR
 TOTAL MASSFL      LB/HR           0.4222759D+05   0.4222759D+05   0.6810302D+04

 CONVERGENCE BLOCK:  CONV1
       TEAR STREAMS: BFW        LSTM
       MAXIT=   30 WAIT    1 ITERATIONS BEFORE ACCELLERATING
       ACCELLERATE EVERY   0 ITERS.  QMAX=    0.0    QMIN=  -5.000
     CONV1     (WEGSTN   ) ITER=  5    *** CONVERGED ***
                                            X              OLD X            ERROR
 TOTAL MOLEFLOW    LBMOL/HR        0.4222759D+05   0.4222478D+05   0.2810708D+01
 TOTAL MOLEFLOW    LBMOL/HR        0.1266828D+06   0.1266856D+06   -.2810708D+01
 H2O MOLEFLOW      LBMOL/HR        0.4222759D+05   0.4222478D+05   0.2810708D+01
 PRESSURE          PSI             0.3100000D-04   0.3100000D-04   0.2012803D-20
 MASS ENTHALPY     BTU/HR          -.5283237D+00   -.5283237D+00   0.8849213D-08
 H2O MOLEFLOW      LBMOL/HR        0.1266828D+06   0.1266856D+06   -.2810708D+01
 PRESSURE          PSI             0.2600000D-04   0.2600000D-04   0.2012803D-20
 MASS ENTHALPY     BTU/HR          -.4847335D+00   -.4847335D+00   -.4735298D-16
1 ASPEN VERSION ONE       SEQUENCE     1                       DATE: 05/27/80   PAGE     3
                                 STEAM POWER CYCLE
                                  FLOWSHEET SECTION

  FORTRAN BLOCK:  X-CALC

    SAMPLED VARIABLES:
      HAO       IS MOLE ENTHALPY     IN STREAM CASCADE   SUBSTREAM MIXED
      HAI       IS MOLE ENTHALPY     IN STREAM XTRACT    SUBSTREAM MIXED
      HBO       IS MOLE ENTHALPY     IN STREAM DAW       SUBSTREAM MIXED
      HBI       IS MOLE ENTHALPY     IN STREAM BFW       SUBSTREAM MIXED
      X1        IS                   IN BLOCK SPLIT
      X2        IS                   IN BLOCK SPLIT

    FORTRAN STATEMENTS:
           WRITE(NHSTRY,*) HAO,HAI,HBO,HBI
```

```
          X1 = (HBO-HBI)/(HAI-HAO)
          X2 = 1-X1
          WRITE(NHSTRY,*) X1,X2

 FORTRAN BLOCK:  P1WORK

   SAMPLED VARIABLES:
     P1I      IS PRESSURE          IN STREAM CONDSTM  SUBSTREAM MIXED
     P1O      IS PRESSURE          IN STREAM P1STM    SUBSTREAM MIXED
     F1       IS TOTAL MASSFLOW    IN STREAM CONDSTM  SUBSTREAM MIXED
     D1       IS MASS DENSITY      IN STREAM CONDSTM  SUBSTREAM MIXED
     WIII     IS STREAM            IN STREAM WP1      SUBSTREAM

   FORTRAN STATEMENTS:
          WIII(1) = (P1O-P1I)*F1/D1
          WRITE(NHSTRY,*) P1O,P1I,F1,D1
          WRITE(NHSTRY,*) WIII(1)

 FORTRAN BLOCK:  P2WORK

   SAMPLED VARIABLES:
     P2I      IS PRESSURE          IN STREAM HWFLOW   SUBSTREAM MIXED
     P2O      IS PRESSURE          IN STREAM BFW      SUBSTREAM MIXED
     F2       IS TOTAL MASSFLOW    IN STREAM HWFLOW   SUBSTREAM MIXED
     D2       IS MASS DENSITY      IN STREAM HWFLOW   SUBSTREAM MIXED
     WIV      IS STREAM            IN STREAM WP2      SUBSTREAM

   FORTRAN STATEMENTS:
          WIV(1) = (P2O-P2I)*F2/D2
          WRITE(NHSTRY,*) P2O,P2I,F2,D2
          WRITE(NHSTRY,*) WIV(1)
1 ASPEN VERSION ONE      SEQUENCE    1                 DATE: 05/27/80  PAGE   4
                                STEAM POWER CYCLE
                                 FLOWSHEET SECTION

 COMPUTATIONAL SEQUENCE

 SEQUENCE USED WAS:
   CONV1 FWHTRB ECON MIXR EVAP VLSEP SHTR CONV2 HPTURB SPLIT FWHTRA RHTR
   LPTURB CONDS PMP1 P1WORK HOTWELL PMP2 P2WORK X-CALC CONV2<--- CONV1<---
   PMP1COST PMP2COST ECONCOST EVAPCOST SHCOST RHCOST FWHTCOST CONDCOST
   HWCOST CONV3 *ECONOMIC CONV3<---

 OVERALL FLOWSHEET BALANCE
    TOTAL BALANCE
       MASS(          )        0.0            0.0            0.0
       ENTHALPY(BTU/HR  )      0.0            0.0            0.0
    TOTAL BALANCE
       MOLE(          )        0.0            0.0            0.0
       ENTHALPY(BTU/HR  )      0.0            0.0            0.0
1 ASPEN VERSION ONE      SEQUENCE    1                 DATE: 05/27/80  PAGE   5
                                STEAM POWER CYCLE
                                U-O-S BLOCK SECTION

 GENERAL-HEAT (HEATER):  ECON
```

INPUT STREAM: DAW OUTPUT STREAM: HSTM
PROPERTY OPTION SET 5

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
H2O	0.4222478D+05	0.4222478D+05	0.0
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.4222478D+05	0.4222478D+05	0.0
ENTHALPY(BTU/HR)	-.4855474D+10	-.4645854D+10	0.4317187D-01

*** INPUT DATA ***

TWO PHASE PV FLASH		
SPECIFIED PRESSURE	PSI	2600.0
VAPOR FRACTION		.0
MAXIMUM ITERATION NO.		30
CONVERGENCE TOLERANCE		.10000D-03

*** RESULTS ***

OUTPUT TEMPERATURE	F	674.61
OUTPUT PRESSURE	PSI	2600.0
HEAT DUTY	BTU/HR	.20962D+09
VAPOR FRACTION		.0

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	1.0001

MIXER (MIXER): MIXR
INLET STREAM(S): LSTM HSTM
OUTLET STREAM: FWTR
PROPERTY OPTION SET 5

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
H2O	0.1689076D+06	0.1689104D+06	-.1664051D-04
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.1689076D+06	0.1689104D+06	-.1664051D-04
ENTHALPY(BTU/HR)	-.1858442D+11	-.1858473D+11	-.1657243D-04

*** INPUT DATA ***

OUTLET PRESSURE	PSI	2600.00
TYPE OF FLASH -	PHASE	
MAXIMUM NUMBER OF ITERATIONS IN FLASH		14
CONVERGENCE TOLERANCE FOR FLASH		.100000D-03

GENERAL-HEAT (HEATER): EVAP
INPUT STREAM: FWTR OUTPUT STREAM: VLSTM
PROPERTY OPTION SET 5

GENERAL-HEAT (HEATER): EVAP (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
H2O	0.1689104D+06	0.1689104D+06	0.0
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.1689104D+06	0.1689104D+06	0.0
ENTHALPY(BTU/HR)	-.1858473D+11	-.1832662D+11	0.1388817D-01

*** INPUT DATA ***

TWO PHASE PV FLASH		
SPECIFIED PRESSURE	PSI	2600.0
VAPOR FRACTION		.25000
MAXIMUM ITERATION NO.		30
CONVERGENCE TOLERANCE		.10000D-03

*** RESULTS ***

OUTPUT TEMPERATURE	F	674.60
OUTPUT PRESSURE	PSI	2600.0
HEAT DUTY	BTU/HR	.25811D+09
VAPOR FRACTION		.25000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	1.0000

FLASH:2-OUTL (FLASH2): VLSEP
INPUT STREAM(S): VLSTM
OUTPUT STREAM(S): VSTM LSTM
PROPERTY OPTION SET 5

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
H2O	0.1689104D+06	0.1689104D+06	0.1723034D-15
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.1689104D+06	0.1689104D+06	0.1723034D-15
ENTHALPY(BTU/HR)	-.1832662D+11	-.1832662D+11	-.1531832D-11

*** INPUT DATA ***

TWO PHASE PQ FLASH		
PRESSURE DROP	PSI	.0
SPECIFIED HEAT DUTY	BTU/HR	.0
MAXIMUM ITERATION NO.		30
CONVERGENCE TOLERANCE		.10000D-03

```
   LIQUID ENTRAINMENT                                              .0
   SOLID SPLIT FRACTIONS:
   SUBSTREAM NO. =    1   MIXED SUBSTREAM, NO SOLID SPLITS.
1 ASPEN VERSION ONE       SEQUENCE    1                   DATE: 05/27/80  PAGE    7
                               STEAM POWER CYCLE
                               U-O-S BLOCK SECTION

 FLASH:2-OUTL (FLASH2):  VLSEP (CONTINUED)

                          ***  RESULTS  ***
   OUTPUT TEMPERATURE     F                                       674.60
   OUTPUT PRESSURE        PSI                                     2600.0
   HEAT DUTY              BTU/HR                                  .0
   VAPOR FRACTION                                                 .25000


      V-L PHASE EQUILIBRIUM :

      COMP              F(I)          X(I)           Y(I)           K(I)
      H2O               1.0000        1.0000         1.0000         1.0000


 GENERAL-HEAT (HEATER):  SHTR
   INPUT STREAM: VSTM         OUTPUT STREAM: SHSTM
   PROPERTY OPTION SET  5

                      ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT           RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       H2O                   0.4222759D+05   0.4222759D+05   0.0
    TOTAL BALANCE
       MOLE(LBMOL/HR)        0.4222759D+05   0.4222759D+05   0.0
       ENTHALPY(BTU/HR  )    -.4388055D+10   -.4118025D+10   0.6153738D-01

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                        1000.0
   SPECIFIED PRESSURE    PSI                                      2500.0
   MAXIMUM ITERATION NO.                                          30
   CONVERGENCE TOLERANCE                                          .10000D-03
   TP FLASH,   NO INITIAL GUESSES ARE REQUIRED.

                           ***  RESULTS  ***
   OUTPUT TEMPERATURE     F                                       1000.0
   OUTPUT PRESSURE        PSI                                     2500.0
   HEAT DUTY              BTU/HR                                  .27003D+09
   VAPOR FRACTION                                                 1.0000


      V-L PHASE EQUILIBRIUM :

      COMP              F(I)          X(I)           Y(I)           K(I)
```

```
     H2O               1.0000          1.0000          1.0000          0.0470


 COMPR-TURBIN (COMPR ):  HPTURB
     INLET  = SHSTM
     OUTLET = HPXSTM
    PROPERTY OPTION SET  5
1 ASPEN VERSION ONE      SEQUENCE    1                  DATE: 05/27/80  PAGE   8
                              STEAM POWER CYCLE
                              U-O-S BLOCK SECTION

 COMPR-TURBIN (COMPR ):  HPTURB (CONTINUED)

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN               OUT          RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       H2O                     0.4222759D+05   0.4222759D+05   0.0
    TOTAL BALANCE
       MOLE(LBMOL/HR)          0.4222759D+05   0.4222759D+05   0.0
       ENTHALPY(BTU/HR  )      -.4118025D+10   -.4235180D+10   -.2844932D-01

                            ***  INPUT DATA  ***

    TYPE : ISENTROPIC TURBINE
    OUTLET PRESSURE ,PSI                                 580.000
    ISENTROPIC EFFICIENCY                                  0.87000
    MECHANICAL EFFICIENCY                                  1.00000

                            ***  RESULTS  ***

    INDICATED  HORSEPOWER, HP                          46,043.6
    BRAKE      HORSEPOWER, HP                          46,043.6
    ISENTROPIC HORSEPOWER, HP                          52,923.7
    CALCULATED OUTLET TEMP, F                             617.713
    ISENTROPIC TEMPERATURE, F                             582.338

 GENERAL-HEAT (HEATER):  RHTR
   INPUT STREAM: RHFLOW       OUTPUT STREAM: RHSTM
   PROPERTY OPTION SET  5

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN               OUT          RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       H2O                     0.2867214D+05   0.2867214D+05   -.2744131D-06
    TOTAL BALANCE
       MOLE(LBMOL/HR)          0.2867214D+05   0.2867214D+05   -.2744131D-06
       ENTHALPY(BTU/HR  )      -.2875647D+10   -.2764575D+10   0.3862512D-01

                           ***  INPUT DATA  ***
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED TEMPERATURE F                                  1000.0
   SPECIFIED PRESSURE    PSI                                560.00
   MAXIMUM ITERATION NO.                                    30
   CONVERGENCE TOLERANCE                                    .10000D-03
```

```
  TP FLASH,    NO INITIAL GUESSES ARE REQUIRED.
1 ASPEN VERSION ONE       SEQUENCE    1              DATE: 05/27/80  PAGE    9
                                  STEAM POWER CYCLE
                                  U-O-S BLOCK SECTION

 GENERAL-HEAT (HEATER):  RHTR (CONTINUED)

                               ***  RESULTS  ***
   OUTPUT TEMPERATURE     F                                     1000.0
   OUTPUT PRESSURE        PSI                                   560.00
   HEAT DUTY              BTU/HR                                .11107D+09



 COMPR-TURBIN (COMPR ):  LPTURB
     INLET  = RHSTM
     OUTLET = LPXSTM
    PROPERTY OPTION SET  5

                          ***  MASS AND ENERGY BALANCE  ***
                                      IN               OUT          RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       H2O                     0.2867214D+05   0.2867214D+05   0.0
    TOTAL BALANCE
       MOLE(LBMOL/HR)          0.2867214D+05   0.2867214D+05   0.0
       ENTHALPY(BTU/HR  )      -.2764575D+10   -.2995603D+10   -.8356733D-01

                               ***  INPUT DATA  ***

    TYPE : ISENTROPIC TURBINE
    OUTLET PRESSURE ,PSI                                        1.72000
    ISENTROPIC EFFICIENCY                                       0.85000
    MECHANICAL EFFICIENCY                                       1.00000

                               ***  RESULTS  ***

    INDICATED  HORSEPOWER, HP                              90,797.5
    BRAKE      HORSEPOWER, HP                              90,797.5
    ISENTROPIC HORSEPOWER, HP                             106,821.
    CALCULATED OUTLET TEMP, F                                  120.383
    ISENTROPIC TEMPERATURE, F                                  120.383

 GENERAL-HEAT (HEATER):  CONDS
   INPUT STREAM: LPXSTM       OUTPUT STREAM: CONDSTM
   PROPERTY OPTION SET  5

                          ***  MASS AND ENERGY BALANCE  ***
                                      IN               OUT          RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       H2O                     0.2867214D+05   0.2867214D+05   0.1268820D-15
    TOTAL BALANCE
       MOLE(LBMOL/HR)          0.2867214D+05   0.2867214D+05   0.6344100D-16
       ENTHALPY(BTU/HR  )      -.2995603D+10   -.3503213D+10   -.1694517D+00
1 ASPEN VERSION ONE       SEQUENCE    1              DATE: 05/27/80  PAGE   10
```

STEAM POWER CYCLE
U-O-S BLOCK SECTION

GENERAL-HEAT (HEATER): CONDS (CONTINUED)

*** INPUT DATA ***

TWO PHASE PV FLASH		
SPECIFIED PRESSURE	PSI	1.7180
VAPOR FRACTION		.0
MAXIMUM ITERATION NO.		30
CONVERGENCE TOLERANCE		.10000D-03

*** RESULTS ***

OUTPUT TEMPERATURE	F	120.34
OUTPUT PRESSURE	PSI	1.7180
HEAT DUTY	BTU/HR	-.50761D+09
VAPOR FRACTION		.0

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	1.0000

MIXER (MIXER): HOTWELL
INLET STREAM(S): P1STM CASCADE
OUTLET STREAM: HWFLOW
PROPERTY OPTION SET 5

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
H2O	0.4222759D+05	0.4222759D+05	0.8615170D-16
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.4222759D+05	0.4222759D+05	0.4307585D-16
ENTHALPY(BTU/HR)	-.5070178D+10	-.5070177D+10	0.1579877D-06

*** INPUT DATA ***

OUTLET PRESSURE	PSI	500.000
TYPE OF FLASH -	PHASE	
MAXIMUM NUMBER OF ITERATIONS IN FLASH		14
CONVERGENCE TOLERANCE FOR FLASH		.100000D-03

GENERAL-HEAT (HEATER): FWHTRA
INPUT STREAM: XTRACT OUTPUT STREAM: CASCADE
PROPERTY OPTION SET 5

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
H2O	0.1355546D+05	0.1355545D+05	0.5804311D-06
TOTAL BALANCE			

MOLE(LBMOL/HR)	0.1355546D+05	0.1355545D+05	0.5804311D-06
ENTHALPY(BTU/HR)	-.1567724D+10	-.1567737D+10	-.8282327D-05

GENERAL-HEAT (HEATER): FWHTRA (CONTINUED)

*** INPUT DATA ***

TWO PHASE PV FLASH		
SPECIFIED PRESSURE	PSI	500.00
VAPOR FRACTION		.0
MAXIMUM ITERATION NO.		30
CONVERGENCE TOLERANCE		.10000D-03

*** RESULTS ***

OUTPUT TEMPERATURE	F	468.07
OUTPUT PRESSURE	PSI	500.00
HEAT DUTY	BTU/HR	-.20821D+09
VAPOR FRACTION		.0

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	.99999

GENERAL-HEAT (HEATER): FWHTRB
INPUT STREAM: BFW   OUTPUT STREAM: DAW
PROPERTY OPTION SET 5

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
H2O	0.4222759D+05	0.4222478D+05	0.6656094D-04
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.4222759D+05	0.4222478D+05	0.6656094D-04
ENTHALPY(BTU/HR)	-.5064003D+10	-.4855474D+10	0.4117661D-01

*** INPUT DATA ***

ONE PHASE TP FLASH	SPECIFIED PHASE IS LIQUID	
SPECIFIED TEMPERATURE	F	500.00
SPECIFIED PRESSURE	PSI	3000.0
MAXIMUM ITERATION NO.		30
CONVERGENCE TOLERANCE		.10000D-03

TP FLASH,   NO INITIAL GUESSES ARE REQUIRED.

*** RESULTS ***

OUTPUT TEMPERATURE	F	500.00
OUTPUT PRESSURE	PSI	3000.0
HEAT DUTY	BTU/HR	.20819D+09

```
1 ASPEN VERSION ONE      SEQUENCE    1                  DATE: 05/27/80   PAGE  12
                              STEAM POWER CYCLE
                                 STREAM SECTION

 DESCRIPTION OF STREAM CLASS HEAT

 STREAM CLASS :  HEAT

 STREAM ATTR  :  HEAT

 DESCRIPTION OF STREAM CLASS WORK

 STREAM CLASS :  WORK

 STREAM ATTR  :  WORK

 DESCRIPTION OF STREAM CLASS CONVEN

 STREAM CLASS :  CONVEN

 SUBSTREAMS   :  MIXED

 SUBSTRM CLASS:  MIXED
1 ASPEN VERSION ONE      SEQUENCE    1                  DATE: 05/27/80   PAGE  13
                              STEAM POWER CYCLE
                                 STREAM SECTION

 QECON QEVAP QSHTR QRHTR QCONDS

 STREAM ID                 QECON      QEVAP      QSHTR      QRHTR      QCONDS
 FROM :                    ECON       EVAP       SHTR       RHTR       CONDS
 TO   :
 CLASS:                    HEAT       HEAT       HEAT       HEAT       HEAT

 STREAM ATTRIBUTES:
 HEAT                    -.61434+08-.75644+08-.79138+08-.32552+08 .14877+09
1 ASPEN VERSION ONE      SEQUENCE    1                  DATE: 05/27/80   PAGE  14
                              STEAM POWER CYCLE
                                 STREAM SECTION

 QFWHTR

 STREAM ID                 QFWHTR
 FROM :                    FWHTRB
 TO   :                    FWHTRA
 CLASS:                    HEAT

 STREAM ATTRIBUTES:
 HEAT                    -.61015+08
1 ASPEN VERSION ONE      SEQUENCE    1                  DATE: 05/27/80   PAGE  15
                              STEAM POWER CYCLE
                                 STREAM SECTION
```

WHPTURB WLPTURB WP1 WP2

STREAM ID	WHPTURB	WLPTURB	WP1	WP2
FROM :	HPTURB	LPTURB	PMP1	PMP2
TO :				
CLASS:	WORK	WORK	WORK	WORK
STREAM ATTRIBUTES:				
WORK	.34335+08	.67708+08	.22620+06	.18093+07

1 ASPEN VERSION ONE SEQUENCE 1 DATE: 05/27/80 PAGE 16

STEAM POWER CYCLE

STREAM SECTION

HSTM FWTR VLSTM VSTM LSTM

STREAM ID	HSTM	FWTR	VLSTM	VSTM	LSTM
FROM :	ECON	MIXR	EVAP	VLSEP	VLSEP
TO :	MIXR	EVAP	VLSEP	SHTR	MIXR
CLASS:	CONVEN	CONVEN	CONVEN	CONVEN	CONVEN
SUBSTREAM: MIXED	STRUCTURE: CONVENTIONAL				
H2O LBMOL/HR	.42225+05	.16891+06	.16891+06	.42228+05	.12668+06
TOTAL LBMOL/HR	.42225+05	.16891+06	.16891+06	.42228+05	.12668+06
TEMP F	674.6108	674.5961	674.5961	674.5961	674.5961
PRES PSI	2600.0000	2600.0000	2600.0000	2600.0000	2600.0000
ENTHALPY BTU/LBMOL	-.11003+06	-.11003+06	-.10850+06	-.10391+06	-.11003+06
VFRAC	0.0	.26030-04	0.2500	1.0000	0.0
LFRAC	1.0000	0.9999	0.7500	0.0	1.0000
ENTROPY BTU/LBMOL-R	-1.2797	-1.2797	-1.2046	-0.9794	-1.2797
DENSITY LB/CUFT	33.9150	33.9148	18.9654	8.1659	33.9176
AVG MW	18.0150	18.0150	18.0150	18.0150	18.0150

1 ASPEN VERSION ONE SEQUENCE 1 DATE: 05/27/80 PAGE 17

STEAM POWER CYCLE

STREAM SECTION

SHSTM HPXSTM RHFLOW XTRACT RHSTM

STREAM ID	SHSTM	HPXSTM	RHFLOW	XTRACT	RHSTM
FROM :	SHTR	HPTURB	SPLIT	SPLIT	RHTR
TO :	HPTURB	SPLIT	RHTR	FWHTRA	LPTURB
CLASS:	CONVEN	CONVEN	CONVEN	CONVEN	CONVEN
SUBSTREAM: MIXED	STRUCTURE: CONVENTIONAL				
H2O LBMOL/HR	.42228+05	.42228+05	.28672+05	.13555+05	.28672+05
TOTAL LBMOL/HR	.42228+05	.42228+05	.28672+05	.13555+05	.28672+05
TEMP F	1000.0000	617.7132	617.7132	617.7132	1000.0000
PRES PSI	2500.0000	580.0000	580.0000	580.0000	560.0000
ENTHALPY BTU/LBMOL	-.97520+05	-.10029+06	-.10029+06	-.10029+06	-.96420+05
VFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
LFRAC	0.0	0.0	0.0	0.0	0.0
ENTROPY BTU/LBMOL-R	-13.0492	-13.0492	-13.0492	-13.0492	-9.5034
DENSITY LB/CUFT	3.2594	0.0551	0.0551	0.0551	0.6609
AVG MW	18.0150	18.0150	18.0150	18.0150	18.0150

STEAM POWER CYCLE
STREAM SECTION

LPXSTM CONDSTM P1STM HWFLOW BFW

STREAM ID		LPXSTM	CONDSTM	P1STM	HWFLOW	BFW
FROM :		LPTURB	CONDS	PMP1	HOTWELL	PMP2
TO :		CONDS	PMP1	HOTWELL	PMP2	FWHTRB
CLASS:		CONVEN	CONVEN	CONVEN	CONVEN	CONVEN
SUBSTREAM: MIXED		STRUCTURE: CONVENTIONAL				
H2O	LBMOL/HR	.28672+05	.28672+05	.28672+05	.42228+05	.42228+05
TOTAL	LBMOL/HR	.28672+05	.28672+05	.28672+05	.42228+05	.42228+05
TEMP	F	120.3831	120.3409	120.5643	236.2500	238.7827
PRES	PSI	1.7200	1.7180	500.0000	500.0000	3100.0000
ENTHALPY	BTU/LBMOL	-.10448+06	-.12218+06	-.12215+06	-.12007+06	-.11992+06
VFRAC		0.9585	0.0	0.0	0.0	0.0
LFRAC		0.0414	1.0000	1.0000	1.0000	1.0000
ENTROPY	BTU/LBMOL-R	-9.5034	-2.0856	-2.0857	-1.9037	-1.9037
DENSITY	LB/CUFT	.28777-03	61.7063	61.7966	59.2848	59.7594
AVG MW		18.0150	18.0150	18.0150	18.0150	18.0150

STEAM POWER CYCLE
STREAM SECTION

CASCADE DAW

STREAM ID		CASCADE	DAW
FROM :		FWHTRA	FWHTRB
TO :		HOTWELL	ECON
CLASS:		CONVEN	CONVEN
SUBSTREAM: MIXED		STRUCTURE: CONVENTIONAL	
H2O	LBMOL/HR	.13555+05	.42225+05
TOTAL	LBMOL/HR	.13555+05	.42225+05
TEMP	F	468.0713	500.0000
PRES	PSI	500.0000	3000.0000
ENTHALPY	BTU/LBMOL	-.11565+06	-.11499+06
VFRAC		0.0	0.0
LFRAC		1.0000	1.0000
ENTROPY	BTU/LBMOL-R	-1.6007	-1.5715
DENSITY	LB/CUFT	50.5921	50.1257
AVG MW		18.0150	18.0150

APPENDIX 3: ECONOMIC EVALUATION RESULTS


```
1
 ASPEN BEGINS EXECUTION FOR STEAM POWER CYCLE

 CALCULATION SEQUENCE ENTERED    TIME =      0.02/     0.03
   3447378.64999999944       11845.1930413999962        8.81985161034269849       988.440468379551248
   30655.2556902266360
   21373747.6299999952       3447378.64999999944        12.5997880147752810       952.857407177306925
   237043.284043667896
  -115653.663869586482      -100294.140298107275      -114991.102866219328      -120058.714957471166
   .329932895878475407       .670067104121524593
   3447378.64999999944       11845.1930413999962        .844270345770513075E-01  988.440468379551248
   293.443976890961551
   21373747.6299999952       3447378.64999999944        .125997879999999882       948.270368033292357
   2381.89925966183955
  -115653.663869586482      -100294.140298107275      -114991.102866219298      -119863.433533982985
   .317218867179644815       .682781132820355185


 ********************************************************************
 *  PHYSICAL PROPERTY ERROR PRINTING LIMIT OF  200 REACHED           *
 *  ERRORS WILL CONTINUE TO BE COUNTED BUT NO MORE WILL BE PRINTED   *
 ********************************************************************


   3447378.64999999944       11845.1930413999962        64.0817884039582673       988.440468379551248
   222729.779978011647
   21373747.6299999952       3447378.64999999944        93.8540702483333504       950.235896070456477
   1770573.70754357893
  -115653.663869586482      -100294.140298107275      -114991.102866219284      -119946.384338782475
   .322619477713784936       .677380522286215064
   3447378.64999999944       11845.1930413999962        64.7013444891936587       988.440468379551248
   224883.177908772166
   21373747.6299999952       3447378.64999999944        95.5169839705772432       949.404065998298563
   1803523.66272294940
  -115653.663869586482      -100294.140298107275      -114991.102866219269      -119911.149702182476
   .320325484906259950       .679674515093740050
   3447378.64999999944       11845.1930413999962        65.3955121202807739       988.440468379551248
   227295.904013812324
   21373747.6299999952       3447378.64999999944        96.2159249288043021       949.757955683442617
   1816043.93172422913
  -115653.663869586482      -100294.140298107275      -114991.102866219255      -119926.116313535720
   .321299903890260849       .678700096109739151
   3447378.64999999944       11845.1930413999962        65.0918514078298180       988.440468379551248
   226240.467120481335
   21373747.6299999952       3447378.64999999944        95.9066482838763186       949.607734392725376
   1810492.79876739439
  -115653.663869586482      -100294.140298107275      -114991.102866219240      -119919.758976073703
   .320886001894380740       .679113998105619260
   3447378.64999999944       11845.1930413999962        22.7004061673269319       988.440468379551248
   78900.0525264353928
   21373747.6299999952       3447378.64999999944        33.4265031064732128       949.671561709124546
   630971.645943936295
  -115653.663869586482      -100294.140298107275      -114991.102866219328      -119922.459374575847
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  .321061814541790641     .678938185458209359
  3447378.64999999944     11845.1930413999962     54.9640467176185581     988.440468379551248
  191039.144459335192
  21373747.6299999952     3447378.64999999944     80.9558924433213285     949.644453126249800
  1528198.46866544732
 -115653.663869581535    -100294.140298107275    -114991.102866219298    -119921.312330493893
  .320987134876435223     .679012865123564777
  3447378.64999999944     11845.1930413999962     65.0838359001477151     988.440468379551248
  226212.607531869478
  21373747.6299999952     3447378.64999999944     95.8506668180785297     949.655968586743825
  1809344.09638575139
 -115653.663869581535    -100294.140298107275    -114991.102866219284    -119921.799558791274
  .321018856452637003     .678981143547362997
  3447378.64999999944     11845.1930413999962     33.2921728319218317     988.440468379551248
  115713.972948137307
  21373747.6299999952     3447378.64999999944     49.0325440526751457     949.651077287208238
  925577.296481627025
 -115653.663869581535    -100294.140298107275    -114991.102866219328    -119921.592599542884
  .321005382125294100     .678994617874705900
  3447378.64999999944     11845.1930413999962     65.0833329260161619     988.440468379551248
  226210.859339123213
  21373747.6299999952     3447378.64999999944     95.8525019384261192     949.653154976537166
  1809384.09818355669
 -115653.663869581535    -100294.140298107275    -114991.102866219298    -119921.680509324942
  .321011105595926383     .678988894404073617
  3447378.64999999944     11845.1930413999962     64.9966312051918891     988.440468379551248
  225909.509210110380
  21373747.6299999952     3447378.64999999944     95.7256175187331984     949.652272442920946
  1806990.61148437764
 -115653.663869581535    -100294.140298107275    -114991.102866219328    -119921.643168013048
  .321008674445523209     .678991325554476791
  3447378.64999999944     11845.1930413999962     65.0772448805524952     988.440468379551248
  226189.699052239972
  21373747.6299999952     3447378.64999999944     95.8440004037006048     949.652647316074479
  1809224.58396954834
 -115653.663869581535    -100294.140298107275    -114991.102866219298    -119921.659029428614
  .321009707121798715     .678990292878201285
  3447378.64999999944     11845.1930413999962     65.0814777889725207     988.440468379551248
  226204.411418803720
  21373747.6299999952     3447378.64999999944     95.8503802949756718     949.652488081839977
  1809345.31905630883
 -115653.663869581535    -100294.140298107275    -114991.102866219328    -119921.652291998995
  .321009268473450196     .678990731526549804
  3447378.64999999944     11845.1930413999962     65.0815198335835383     988.440468379551248
  226204.557553722771
  21373747.6299999952     3447378.64999999944     95.8503802949756718     949.652555719515135
  1809345.19018821907
 -115653.663869581535    -100294.140298107275    -114991.102866219328    -119921.655153845059
  .321009454797332602     .678990545202667398

ENTERING COST BLOCK PMP1COST  ROUTINE: CPC01   INTERFACE: CPC01I  MODEL: CPC01     TIME =     8.53/     8.58
 *   WARNING          8754103 ROUTINE: CPC01   BLOCK: PMP1COST
     PUMP HEAD, 3.471D+03, TOO HIGH. EXTRAPOLATION OVER 3.300D+03 M2/S2 REQUIRED
 *   WARNING          8754106 ROUTINE: CPC01   BLOCK: PMP1COST
     NOMINAL MOTOR SIZE, 4.000D+02, TOO HIGH. MAXIMUM FOR PUMP TYPE 2.500D+02 HP
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 *    WARNING          8754105 ROUTINE: CPC01    BLOCK: PMP1COST
      PUMP SIZE, 3.879D+00, TOO HIGH. MAXIMUM FOR PUMP TYPE 3.700D+00 M4/S2

      PUMP COSTING RESULTS:

      # OF PUMPS             1  BASE COST  2.002D+04  TOTAL COST 2.549D+04
 *    WARNING          8759802 ROUTINE: CUTRQ    BLOCK: PMP1COST
      NUMBER OF UTILITIES SPECIFIED BY THE USER IS NOT EQUAL TO THAT OF REQUIRED

 ENTERING COST BLOCK PMP2COST  ROUTINE: CPC01   INTERFACE: CPC01I  MODEL: CPC01      TIME =      8.54/     8.60
 *    WARNING          8754101 ROUTINE: CPC01    BLOCK: PMP2COST
      FLOW PER PUMP, 1.009D-01, TOO HIGH. EXTRAPOLATION OVER 6.940D-02 M3/S REQUIRED
 *    WARNING          8754107 ROUTINE: CPC01    BLOCK: PMP2COST
      BRAKE POWER, 2.253D+06 W TOO HIGH FOR ELECTRIC MOTOR
 *    WARNING          8754103 ROUTINE: CPC01    BLOCK: PMP2COST
      PUMP HEAD, 1.873D+04, TOO HIGH. EXTRAPOLATION OVER 3.300D+03 M2/S2 REQUIRED
 *    WARNING          8754106 ROUTINE: CPC01    BLOCK: PMP2COST
      NOMINAL MOTOR SIZE, 3.020D+03, TOO HIGH. MAXIMUM FOR PUMP TYPE 2.500D+02 HP
 *    WARNING          8754105 ROUTINE: CPC01    BLOCK: PMP2COST
      PUMP SIZE, 1.381D+01, TOO HIGH. MAXIMUM FOR PUMP TYPE 3.700D+00 M4/S2
 *    WARNING          8754108 ROUTINE: CPC01    BLOCK: PMP2COST
      NOMINAL MOTOR SIZE, 3.020D+03 HP, TOO HIGH. EXTRAPOLATION REQUIRED

      PUMP COSTING RESULTS:

      # OF PUMPS             1  BASE COST  4.015D+04  TOTAL COST 5.964D+04
 *    WARNING          8759802 ROUTINE: CUTRQ    BLOCK: PMP2COST
      NUMBER OF UTILITIES SPECIFIED BY THE USER IS NOT EQUAL TO THAT OF REQUIRED

 ENTERING COST BLOCK ECONCOST  ROUTINE: CHE01   INTERFACE: CHE01I  MODEL: CHE01      TIME =      8.56/     8.61
        HEAT EXCHANGER SIZING RESULTS:
      AREA       1.632D+02  DELTA T LM 2.821D+02  TRAN COEFF 3.407D+03
        HEAT EXCHANGER COSTING
      NO OF EXCH             1  BASE COST  .2308D+05  EXCH. COST .2308D+05

 ENTERING COST BLOCK EVAPCOST  ROUTINE: CHE01   INTERFACE: CHE01I  MODEL: CHE01      TIME =      8.56/     8.62
        HEAT EXCHANGER SIZING RESULTS:
      AREA       8.037D+02  DELTA T LM 1.252D+02  TRAN COEFF 4.543D+03
        HEAT EXCHANGER COSTING
      NO OF EXCH             1  BASE COST  .8499D+05  EXCH. COST .8499D+05

 ENTERING COST BLOCK SHCOST    ROUTINE: CHE01   INTERFACE: CHE01I  MODEL: CHE01      TIME =      8.57/     8.63
        HEAT EXCHANGER SIZING RESULTS:
      AREA       5.218D+02  DELTA T LM 2.403D+02  TRAN COEFF 1.363D+03
        HEAT EXCHANGER COSTING
      NO OF EXCH             1  BASE COST  .5770D+05  EXCH. COST .5770D+05

 ENTERING COST BLOCK RHCOST    ROUTINE: CHE01   INTERFACE: CHE01I  MODEL: CHE01      TIME =      8.57/     8.63
        HEAT EXCHANGER SIZING RESULTS:
      AREA       3.242D+02  DELTA T LM 2.526D+02  TRAN COEFF 5.678D+02
        HEAT EXCHANGER COSTING
      NO OF EXCH             1  BASE COST  .3878D+05  EXCH. COST .3878D+05

 ENTERING COST BLOCK FWHTCOST  ROUTINE: CHE01   INTERFACE: CHE01I  MODEL: CHE01      TIME =      8.58/     8.64
        HEAT EXCHANGER SIZING RESULTS:
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     AREA        2.560D+02  DELTA T LM 9.297D+01   TRAN COEFF 3.407D+03
       HEAT EXCHANGER COSTING
     NO OF EXCH          1  BASE COST  .3221D+05   EXCH. COST .3221D+05

 ENTERING COST BLOCK CONDCOST   ROUTINE: CHE01    INTERFACE: CHE01I  MODEL: CHE01      TIME =       8.59/     8.65
       HEAT EXCHANGER SIZING RESULTS:
     AREA        3.560D+03  DELTA T LM 1.226D+01   TRAN COEFF 3.407D+03
 *   WARNING          8751102 ROUTINE: CHE01    BLOCK: CONDCOST
     AREA IS GREATER THAN MAXIMUM AREA= 3560.         AMAX= 1100.       M2
       HEAT EXCHANGER COSTING
     NO OF EXCH          1  BASE COST  .3703D+06   EXCH. COST .4966D+06

 ENTERING COST BLOCK HWCOST     ROUTINE: CVS11    INTERFACE: CVS01I  MODEL: CVS11      TIME =       8.59/     8.66
       VERTICAL PRESSURE VESSEL SIZING RESULTS:
     NO.VESSELS          1  INNER DIAM 3.048D+00   SHELL WGT   4.788D+04
       VERTICAL PRESSURE VESSEL COSTING RESULTS:
     SHELL WGT   4.788D+04  BASE COST  1.033D+05   TOTAL COST 1.129D+05

 ENTERING CONVERGENCE BLOCK CONV3      ROUTINE: SECANT  INTERFACE: CONVI   MODEL: SECANT     TIME =       8.60/     8.66
 ITER   0 FOR SPECS:          AC-SPEC
               EQUIPMENT COST SUMMARY
```

ID	ITEM	QUAN -TITY	STAND -BY	BASE COST	PURCHASED COST
PMP1COST		1	1	40035.	50984.
PMP2COST		1	1	80293.	119278.
ECONCOST		1	0	23079.	23079.
EVAPCOST		1	0	84993.	84993.
SHCOST		1	0	57696.	57696.
RHCOST		1	0	38778.	38778.
FWHTCOST		1	0	32207.	32207.
CONDCOST		1	0	370328.	496643.
HWCOST		1	0	103273.	112927.

ID	ITEM	MATERIAL COST	LABOR HOURS
PMP1COST		154013.	160.
PMP2COST		342937.	321.
ECONCOST		44127.	92.
EVAPCOST		164377.	340.
SHCOST		114295.	231.
RHCOST		76431.	155.
FWHTCOST		62771.	129.
CONDCOST		837345.	1481.
HWCOST		192035.	413.

```
1     UTILITY INVESTMENT ESTIMATION
                    CAPITAL INVESTMENT

     TOTAL CAPITAL INVESTMENT                 85084191.

1     PROFITABILITY ANALYSIS
1              PROFITABILITY INDICES
```

RATE OF RETURN ON EQUITY	0.20000
OVERALL DISCOUNTED RATE	0.13500
NET PRESENT VALUE INDEX	0.0
RETURN ON INVESTMENT	0.11532
PAYOUT TIME	8.67163
BREAKEVEN FRACTION	0.63208
BREAKEVEN VOLUME, KG/YEAR	8.976D+11

PRODUCT SELLING PRICE

POWER	$/KG	2.529D-05

```
ENTERING CONVERGENCE BLOCK CONV3     ROUTINE: SECANT   INTERFACE: CONVI   MODEL: SECANT     TIME =      8.85/     8.95
ITER   1 FOR SPECS:           AC-SPEC
 .25288191642079690 1E-04   .9999999999999999766E+70   .9999999999999999766E+70
   CONV3     (SECANT  ) ITER=  1
                             NEW X         G(X)            X                ERROR
 1   FISCAL           (3)  100000.00      .0            9300000.0        .63881916D-05*
```

EQUIPMENT COST SUMMARY

ID	ITEM	QUAN -TITY	STAND -BY	BASE COST	PURCHASED COST
PMP1COST		1	1	40035.	50984.
PMP2COST		1	1	80293.	119278.
ECONCOST		1	0	23079.	23079.
EVAPCOST		1	0	84993.	84993.
SHCOST		1	0	57696.	57696.
RHCOST		1	0	38778.	38778.
FWHTCOST		1	0	32207.	32207.
CONDCOST		1	0	370328.	496643.
HWCOST		1	0	103273.	112927.

ID	ITEM	MATERIAL COST	LABOR HOURS
PMP1COST		154013.	160.
PMP2COST		342937.	321.
ECONCOST		44127.	92.
EVAPCOST		164377.	340.
SHCOST		114295.	231.
RHCOST		76431.	155.
FWHTCOST		62771.	129.
CONDCOST		837345.	1481.

```
     HWCOST                                         192035.      413.
     ---------------------------------------------------------------------
1    UTILITY INVESTMENT ESTIMATION
                   CAPITAL INVESTMENT

    TOTAL CAPITAL INVESTMENT                           45406210.

1    PROFITABILITY ANALYSIS
1                PROFITABILITY INDICES


     RATE OF RETURN ON EQUITY               0.20000

     OVERALL DISCOUNTED RATE                0.13500

     NET PRESENT VALUE INDEX                0.0

     RETURN ON INVESTMENT                   0.11578

     PAYOUT TIME                            8.63733

     BREAKEVEN FRACTION                     0.67319

     BREAKEVEN VOLUME, KG/YEAR            9.560D+11



                PRODUCT SELLING PRICE

     POWER     $/KG                       1.549D-05

 ENTERING CONVERGENCE BLOCK CONV3     ROUTINE: SECANT   INTERFACE: CONVI   MODEL: SECANT     TIME =      9.09/     9.22
 ITER   2 FOR SPECS:          AC-SPEC
  .15493433106845078 2E-04   .999999999999999766E+70    .999999999999999766E+70
    CONV3     (SECANT  ) ITER=  2
                                NEW X            G(X)            X                 ERROR
  1   FISCAL          (3)  3299712.9       .0              100000.00       -.34065669D-05*
                EQUIPMENT COST SUMMARY

        ID           ITEM        QUAN   STAND     BASE COST        PURCHASED COST
                                 -TITY   -BY
     ---------------------------------------------------------------------
     PMP1COST                       1      1         40035.           50984.
     PMP2COST                       1      1         80293.          119278.
     ECONCOST                       1      0         23079.           23079.
     EVAPCOST                       1      0         84993.           84993.
     SHCOST                         1      0         57696.           57696.
     RHCOST                         1      0         38778.           38778.
     FWHTCOST                       1      0         32207.           32207.
     CONDCOST                       1      0        370328.          496643.
     HWCOST                         1      0        103273.          112927.
     ---------------------------------------------------------------------
        ID           ITEM          MATERIAL COST      LABOR
                                                      HOURS
```

```
      ------------------------------------------------------------------
      PMP1COST                               154013.      160.
      PMP2COST                               342937.      321.
      ECONCOST                                44127.       92.
      EVAPCOST                               164377.      340.
      SHCOST                                 114295.      231.
      RHCOST                                  76431.      155.
      FWHTCOST                                62771.      129.
      CONDCOST                               837345.     1481.
      HWCOST                                 192035.      413.
      ------------------------------------------------------------------
1     UTILITY INVESTMENT ESTIMATION
                   CAPITAL INVESTMENT

     TOTAL CAPITAL INVESTMENT                       59206009.

1     PROFITABILITY ANALYSIS
1              PROFITABILITY INDICES

      RATE OF RETURN ON EQUITY              0.20000

      OVERALL DISCOUNTED RATE               0.13500

      NET PRESENT VALUE INDEX               0.0

      RETURN ON INVESTMENT                  0.11555

      PAYOUT TIME                           8.65432

      BREAKEVEN FRACTION                    0.65406

      BREAKEVEN VOLUME, KG/YEAR           9.288D+11


              PRODUCT SELLING PRICE

      POWER    $/KG                       1.890D-05

 ENTERING CONVERGENCE BLOCK CONV3    ROUTINE: SECANT  INTERFACE: CONVI  MODEL: SECANT    TIME =     9.32/     9.48
 ITER   3 FOR SPECS:          AC-SPEC
  .18899999999999986E-04  .99999999999999766E+70  .99999999999999766E+70
    CONV3    (SECANT  ) ITER=  3   *** CONVERGED ***
                          NEW X          G(X)           X                ERROR
  1   FISCAL         (3)  3299712.9      .0          3299712.9      .0
               EQUIPMENT COST SUMMARY

        ID          ITEM        QUAN  STAND    BASE COST      PURCHASED COST
                                -TITY  -BY
      ------------------------------------------------------------------
      PMP1COST                    1     1        40035.          50984.
      PMP2COST                    1     1        80293.         119278.
      ECONCOST                    1     0        23079.          23079.
```

EVAPCOST	1	0	84993.	84993.
SHCOST	1	0	57696.	57696.
RHCOST	1	0	38778.	38778.
FWHTCOST	1	0	32207.	32207.
CONDCOST	1	0	370328.	496643.
HWCOST	1	0	103273.	112927.

ID	ITEM	MATERIAL COST	LABOR HOURS
PMP1COST		154013.	160.
PMP2COST		342937.	321.
ECONCOST		44127.	92.
EVAPCOST		164377.	340.
SHCOST		114295.	231.
RHCOST		76431.	155.
FWHTCOST		62771.	129.
CONDCOST		837345.	1481.
HWCOST		192035.	413.

1 UTILITY INVESTMENT ESTIMATION
CAPITAL INVESTMENT

TOTAL CAPITAL INVESTMENT 59206009.

1 PROFITABILITY ANALYSIS
1 PROFITABILITY INDICES

RATE OF RETURN ON EQUITY	0.20000
OVERALL DISCOUNTED RATE	0.13500
NET PRESENT VALUE INDEX	0.0
RETURN ON INVESTMENT	0.11555
PAYOUT TIME	8.65432
BREAKEVEN FRACTION	0.65406
BREAKEVEN VOLUME, KG/YEAR	9.288D+11

PRODUCT SELLING PRICE

POWER $/KG 1.890D-05

CALCULATION SEQUENCE COMPLETED TIME = 9.56/ 9.75

REPORT WRITER ENTERED TIME = 9.56/ 9.77
END OF CONVERGENCE BLOCK CHAIN
NO BLOCKS IN TRANSFER BLOCK CHAIN

```
      END OF FORTRAN BLOCK CHAIN
      END OF UOS BLOCK CHAIN
        VERTICAL PRESSURE VESSEL SIZING RESULTS:
      NO.VESSELS         1  INNER DIAM 3.048D+00  SHELL WGT  4.788D+04
        VERTICAL PRESSURE VESSEL COSTING RESULTS:
      SHELL WGT  4.788D+04  BASE COST  1.033D+05  TOTAL COST 1.129D+05
      END OF COST BLOCK CHAIN
      END OF ECONOMICS BLOCK CHAIN

 REPORT GENERATED   TIME =     10.82/    11.11

                              ***  SUMMARY OF ERRORS  ***

                          PHYSICAL
                          PROPERTY         SYSTEM         SIMULATION
      TERMINAL ERRORS        0               0                0
        SEVERE ERRORS        0               0                0
               ERRORS        0               0                0
             WARNINGS     1151               0               31

 ********************************************
 *  ASPEN SIMULATION PROGRAM ENDS EXECUTION  *
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REFERENCES

ASPEN Users Manual

"Recommendations for the Conceptual Design of the Barstow, California, Solar Central Receiver Pilot Plant", Solar Project Division, Sandia Laboratories, SAND77-80035.

V.W. Uhl, and M.G. Klett, "Typical Costs for Electric Energy Generation and Environmental Controls", paper presented at AICHE meeting, Houston TX, April 2-5, 1979.

Metz, and Hammond, "Solar Energy in America", American Association for the Advancement of Science, 1979.

Zoschak, R.J. and Wu, S.F., "Studies of the Direct Input of Solar Energy to a Fossil Fueled Station Steam Power Plant.", Solar Energy, Vol. 17, pp. 297-305. Pergamon Press, 1975.

"The ASPEN Project Thirteenth Annual Progress Report." September 15, 1979. MIT-2295T9-14

Zoschak, and Wu.

Process Plant Construction Estimating Standards. Vol. 4 - Process Equipment, Richardson Engineering Services, Inc.

1975 General Electric Price Catalogue.

"Marks' Standard Handbook for Mechanical Engineers", 1978 MacGraw Hill, Eighth Edition. pp.17-37.

"Thermal Power Stations - a Techno-Economic Study", United Nations, 1970, N.Y.

Bailey, J.N. "Documentation of Medical Area Total Energy Plant Economic Analysis" Cambridge Associates, January 2, 1980.

ESCOE Report on Coal Conversion Processes, ESCOE, 1979.

Bailey, J.N.

Uhl, V.W.